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Multiple Secondary Effects of the Penetrating Cosmic Radiation at Sea Level

PIERRE AUGER* AND JEAN DAUDIN
University of Paris, France

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The production of multiple secondary particles by cosmic rays under thick layers of lead has been studied with coincidence counters and with a cloud chamber. Part of the coincidences obtained under 15 cm of lead is attributed to groups of particles of atmospheric origin associated with extensive showers. The other part is due to a local effect produced in the lead by single penetrating particles. Among the particles emitted in these processes, some have the penetrating power of low energy mesons.

INTRODUCTION

It is well known[1] that some showers contain penetrating particles and that showers can be produced by the penetrating part of the cosmic radiation observed in the low atmosphere. The tail of the Rossi curve is due to showers produced by particles which have penetrated more than ten centimeters of lead. Showers observed under ground have their direct or indirect origin in the penetrating component of cosmic rays. Nevertheless, the exact relation between penetrating rays and showers is not completely understood. Some information has been obtained in the following experiments by the use of simple geometrical arrangements of coincidence counters and of a cloud chamber.

It has been admitted here that the particles responsible for the counts were only electrons and mesons, and that the distinction between them had to be based on their absorption and their cascade shower production. An electron of high energy, which is able, for instance, to penetrate ten centimeters of lead, is always accompanied by a shower in the atmosphere as well as in lead, and is most probably associated with an extensive shower. On the contrary a meson generally has a high penetrating power without being associated with electrons in free air, and gives rise to showers, with an appreciable probability, only in dense media.

The principal aim here has therefore been the study of the "accompaniment" of the particles responsible for secondary effects, that is to say the number of electrons and photons arriving simultaneously in their close neighborhood (ordinary local showers) or at a distance of a few meters (extensive, or *A* showers).[2] The geometrical characteristics of the secondary effects produced have also been analyzed.

GENERAL ARRANGEMENTS

The counters had an argon-hydrogen filling, and an effective surface of about 100 cm² when

* Research Associate at the University of Chicago.

[1] See, for instance, P. Auger, P. Ehrenfest, A. Fréon, and R. Maze, J. de Phys. **10**, 1 (1939); G. Wataghin, M. D. de Souza Santos, and P. A. Pompeia, Phys. Rev. **57**, 61 (1940); L. Janossy and P. Ingleby, Nature **145**, 511 (1940); Josephson, Froman, and Stearns, Phys. Rev. **57**, 335 (1940); P. Auger and J. Daudin, Comptes rendus **212**, 24 (1941); etc.

[2] The extensive showers of the atmosphere will be referred to as *A* showers. See P. Auger, R. Maze, and T. Grivet-Meyer, Comptes rendus **206**, 1791 (1938); P. Auger, R. Maze, and A. Fréon, J. de Phys. **10**, 39 (1939).

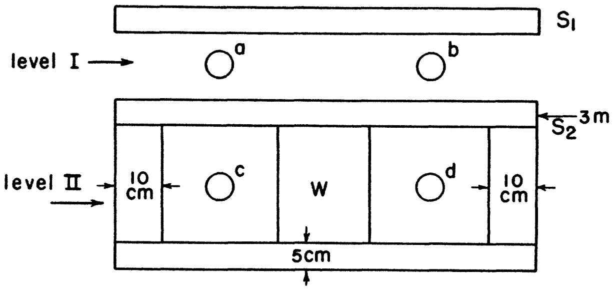

FIG. 1. Arrangement of counters and screens in the absorption measurements on local air showers and on A showers.

horizontal. The coincidence system was of the Maze type. The cloud chamber, originally devised by P. Ehrenfest, had a surface of 28×18 cm and a depth of 3 cm. Most of the experimental work was done by J. Daudin, and details will be published by him later on.

The counters were placed on two horizontal planes marked I and II (Fig. 1) separated by a vertical distance of 25 cm; lead screens could be placed above level I (screen S_1) and between I and II (screen S_2). Lateral protection and protection of the counters from below, on level II, was realized by walls 10 cm thick and by a bottom shield 5 cm thick. A lead wall W could be placed between the counters at level II. When A showers had to be counted, a supplementary unshielded counter was added at level I, from 3 to 5 meters distant. The surface of the counters was sometimes doubled by connecting two of them in parallel. This arrangement will be indicated by the symbol (×2). All these arrangements have been considerably modified in the last set of experiments here described.

ABSORPTION EXPERIMENTS. AIR SHOWERS

Experiments were first made on the penetrating part of ordinary local air showers and of A showers. These two kinds of showers were defined by the coincidences of two unshielded counters in level I, these counters being 5 cm to 20 cm distant (a, b) in one case or 5 m distant (a, e) in the other.

(a) A local shower being defined by the coincidences between the two unshielded counters a b in level I, the triple coincidences with counter c (×2) in level II were measured as a function of the thickness of the interposed screen S_2. The distance between a and b was 5 cm in series 1 and 20 cm in series 2 and 3. The results are shown in Table I and on Fig. 2, curves I, II, III, in which N_3 (number of triple coincidences per hour) is plotted on a logarithmic scale.[3]

(b) An A shower being defined by the coincidence of counters a, b with a third one, e (×2) placed at 3-meters distance, the quadruple coincidences with counter c in level II were measured as a function of the thickness of screen S_2. The results are given in Fig. 2, curve IV, where three separate series are indicated, and in Table II, where only the mean values of the three series are given.

(c) The correlation of the local showers which contain penetrating particles with A showers can

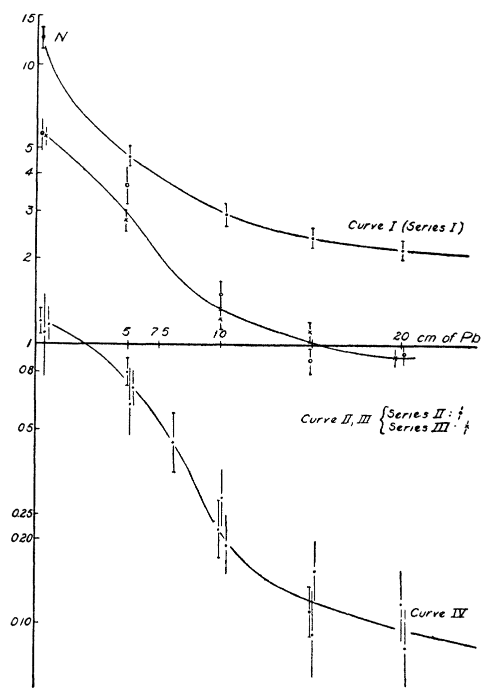

FIG. 2. Absorption curves for local air showers and for A showers. N is the number of coincidences per hour.

[3] The symbols N_3 and N_4 will mean, respectively, "triple coincidences per hour" and "quadruple coincidences per hour" in this paper.

TABLE I. Absorption of local air showers in lead.

Thickness of screen S_2(cm)		0	5	10	15	20
N_3 ($a\ b\ c$)	Series I	12.2±1	4.7 ±0.4	2.9 ±0.2	2.4 ±0.2	2.2 ±0.15
	Series II	5.6±0.8	3.7 ±0.5	1.52±0.18	0.91±0.1	0.95±0.07
	Series III	5.5±0.4	2.74±0.2	1.24±0.11	1.13±0.1	0.91±0.9

TABLE II. Absorption of *A* showers. Correlation with local air showers.

Thickness of screen S_2(cm)	0	5	10	15	20
N_4 ($a\ b\ c\ e$)	1.15±0.1	0.73±0.06	0.22±0.05	0.12±0.02	0.10±0.02
Ratio $\frac{N_4\ (a\ b\ c\ e)}{N_3\ (a\ b\ c)}$	0.22	0.23	0.17	0.12	0.09

TABLE III. Coincidences under lead. Correlation with *A* showers.

Thickness of screen S_2 (cm)	5	10	15
N_3 ($a\ c\ d$)	4.75±0.4	1.8±0.2	1.3±0.1
Ratio $\frac{N_4\ (a\ c\ d\ e)}{N_3\ (a\ c\ d)}$	0.11		0.03

be measured as a function of the minimum penetrating power of these particles, that is to say the thickness of the screen S_2. This correlation is given by the ratio of the number of quadruple coincidences $a\ b\ c\ e$ to the number of triple coincidences $a\ b\ c$. (See Table II, last line.)

Two conclusions can be drawn from these results:

(1) The local air showers, as measured by the triple counts $a\ b\ c$ are markedly more absorbed by the first five centimeters of lead than the single rays which exist at sea level. This shows that local showers contain a greater proportion of electrons and especially of low energy electrons than does the total cosmic radiation at sea level. The narrower showers are the richest in low energy electrons. When the screen S_2 is 20 cm thick, only mesons are responsible for the counts in counter c, directly or indirectly; in this experiment one sixth of the initial number of showers gave a count under that screen.

(2) The *A* showers, as measured by the quadruple counts $a\ b\ c\ e$, contain also a penetrating part.[2] For the first five centimeters of lead the absorption of *A* showers is about the same as for single rays at sea level and smaller than for narrow showers. Between 5 cm and 10 cm and even more markedly between 10 cm and 20 cm lead, the absorption is much larger for the *A* showers than for the ordinary ones. This is probably due to the existence in the *A* showers of a component of intermediate penetrating power. The nature of this component is complex. Electrons of very high energy are present, a point which has been noticed in our cloud-chamber photographs of *A* showers; but only slow mesons could explain the existence of particles requiring 20 cm of lead to be stopped.[4] The number of counts under such a screen is equal only to one-twelfth of the number without a screen, thus showing that the *A* showers contain a smaller proportion of penetrating mesons than the local air showers.

ABSORPTION EXPERIMENTS. SHOWERS UNDER LEAD

Consider now the shower production under lead, in level II. Two counters $c\ d$ are placed at this level, one counter a (×2) remaining at level I. The interposition of a screen of less than 5 cm brings about an increase of the counts due to the well-known cascade shower production. Between 5-cm and 10-cm screen the fall is quite pronounced, indicating the absorption of the highest energy electrons. After 10 cm the decrease is much smaller, as the mesons are probably the only shower producer able to penetrate these thick screens. Results are given in Table III.

The addition of a distant counter e (×2) gives an idea of the correlation of the particles responsible for the shower production under lead with *A* showers. Showers produced under 5 cm of lead give a count in the distant counter in 10 percent of the cases. That means that their producing particles are associated in about 20 percent of the cases with *A* showers. Showers under a shield of 15 cm show a much smaller association; this is due to the fact that penetrating mesons, which

[4] This points out an analogy of composition between the semi-penetrating part of the *A* showers in the low atmosphere, and the soft component of the total cosmic radiation at altitudes of 3 or 4 km. In both cases a considerable amount of slow mesons is added to the electrons of high energy.

TABLE IV. Coincidences under varying thickness of upper screen.

Thickness of screen S_1(cm)	0	1	2	5	10
N_3 (*a c d*)	1.30±0.06	1.33±0.2	1.55±0.15	1.47±0.15	1.28±0.2
Ratio $\frac{N_4\ (a\ b\ c\ d)}{N_3\ (a\ c\ d)}$	0.05	0.09	0.14	0.12	0.15

TABLE V. Coincidences for varying wall thickness.

Thickness of wall (cm)		0	0.5	2	5	10
N_3 (*a c d*)	Series 1	2.05±0.2	0.85±0.2	0.5 ±0.1	0.42±0.1	
	Series 2	—	—	0.67±0.08	0.47±0.06	
	Series 3	—	—	1.65±0.3	1.13±0.15	0.68±0.1

produce most of the showers under thick screens, are not numerous in *A* showers.

EXPERIMENTS ON THE PRODUCTION OF SECONDARY ELECTRONS

One of the important properties of the particles studied here is their capacity for electron production. This may be measured in the air by the association of a counter *b* near the counter *a* which is, in the preceding arrangement, sensitive to the particles producing showers under lead. The fourfold coincidences *a b c d* have been actually measured with a geometrical disposition slightly different from that which gives the numbers in Table III, but the figures may well be compared if we try only to find a qualitative indication. The proportion between the quadruples *a b c d* and the triples *a c d* falls from 40 percent with a screen S_2 of 5-cm lead to 17 percent with a screen of 15 cm. The mesons, which play a greater role in the second case, are also less shower producing in air. They have a small accompaniment of electrons.

The capacity of shower production is easier to measure in a lead screen, and a long series of experiments has been made with the interposition of a variable screen S_1 above the counters in level I, the screen S_2 remaining constant (15 cm) and the counters *c*, *d* in level II being separated by a wall of 2-cm lead. For each value of the thickness of screen S_1 the triple counts *a c d* with one counter at level I and two at level II, and the quadruple counts *a b c d* with two counters in each level, have been measured. We give in Table IV the values for N_3 (triples *a c d* per hour) and the ratio N_4/N_3 (quadruples *a b c d*/triples *a c d*). The interposition of screen S_1 favors the production of secondary electrons and photons by the primaries which are responsible for the showers in level II. The sensitivity of counter *a*, and *a fortiori* of two counters *a b*, for these primaries is increased; the effect is more marked with two counters in level I, and shows saturation for two centimeters lead (like the ordinary shower curve for penetrating rays).

Consider the number of counts *a c d* obtained without shower-producing screen S_1. The addition of counter *b* (×2) at a distance of about 10 cm leaves 5 percent of the coincidences, showing thus a correlation with local showers which is of the same order of magnitude as the correlation with *A* showers. (See Table III.) As the mesons have a very poor accompaniment of electrons in free air, it is natural to attribute the quadruple counts *a b c d* with $S_2 = 5$ cm lead to electrons of very high energy or to mesons coupled with a shower of electrons. Both of these events are likely to happen only within an *A* shower. In order to test this conclusion a fifth counter *e* (×2) has been added at a distance of three meters. This system records quintuple coincidences produced by *A* showers. The ratio of quintuple counts *a b c d e* to quadruple counts *a b c d* was as high as 0.50, a value which can be considered only as an order of magnitude because of the small number of counts per hour (0.3 for the quintuple counts with a 5-cm thick shield S_2).

The rate of production of secondary electrons in the screen S_2 by the penetrating radiation associated with showers in air may also be studied. If the air shower is an electronic cascade, the penetrating part will consist of high energy electrons, and will give rise to a dense shower all along its path in the lead. If, on the contrary, the air shower is secondary to a meson, this particle will constitute the penetrating part, and will remain generally single. The measurements were made by the same arrangement as before, with two unshielded counters *a b* at level I and two counters *c d* at level II separated by a wall of 2-mm lead. The number N_3 of triple counts $a\,b\,c$ and the number N_4 of quadruple counts were measured for different values of the thickness of screen S_2. The ratio $N_4(a\,b\,c\,d)/N_3(a\,b\,c)$ gives the probability for the second counter under lead d to be touched by the penetrating part of the air shower detected by $a\,b$. This probability is as high as 0.25 with a 5-cm screen and decreases to 0.10 with a screen of 15 cm. If there is no screen S_2 at all, the ratio N_4/N_3 reaches 0.40. This value is a consequence of the high density of the air showers selected by a system of three counters. The important part played by the electronic penetrating showers in the case of small thicknesses of lead, and the prominent role of mesons in the shower production under 15-cm lead are clearly shown by these results.

ORIGIN OF THE SHOWERS UNDER LEAD

In the preceding analysis we have admitted that only two types of showers containing a penetrating part were present: electronic cascades of very high energy, associated with showers, and showers of electrons more or less directly produced by a meson. Another possibility, already suggested by different authors, would be found in the existence of showers of mesons, or at least pairs of mesons, created in the atmosphere or in the lead. In order to study the relative importance of these processes, several experiments were made with an arrangement of counters slightly more complicated. The level II was occupied by two chambers separated by a wall W and each containing two counters (Fig. 3). The influence of the thickness of the wall and of the screen S_2, of the disposition of counters in level II and in level I have been studied.

(A) Influence of Wall *W*

Three counters, a in level I, c and d in level II were used; the screen S_2 was 10 cm thick, and the thickness of the wall W could be varied from 0 to 5 cm. The results of three series of measurements are given in Table V. In series 3 the arrangement of counters was modified in order to increase the number of counts. The number of triple coincidences decreases very strongly when 5 mm of lead are interposed between the counters $c\,d$. This points out the existence of a large number of electrons of small energy emitted in very oblique directions, presumably in knock-on showers. The decrease continues when the wall thickness is increased to 2 cm showing the existence of electrons of higher energy; the role of the photons of 10^7 ev, which have a relatively high penetrating power, is also important in these circumstances. But the surprising fact is that an increase of the wall thickness up to 5 cm brings a diminution of about 30 percent of the counts, and that an additional 5 cm determines a reduction of the same order. This means that some of the oblique particles emitted have a penetrating power which is not compatible with an electronic or a photonic nature. The role of multiple penetrating particles coming from the air must be small. It is here limited to the production of the coincidences which are insensitive to the increase of thickness of the wall. They cannot be responsible for more than 25 percent of the effect observed with a 2-cm wall.

(B) Multiple Penetrating Particles from the Air

A fourth counter b (×2) was added on level I. When this counter was situated in b_2 just above d the arrangement could be considered as specially sensitive to parallel penetrating particles coming from the air. Table VI shows that the ratio of quadruple counts $a\,b_2\,c\,d$ to triple counts $a\,c\,d$ increases when the thickness of the wall is increased from 0 to 5 cm. When counter b was situated in b_1, thus necessitating three particles, the ratio $N_4(a\,b_1\,c\,d)/N_3(a\,c\,d)$ was notably reduced.

Since the number of quadruple counts per hour are very small in these arrangements, (0.2 with

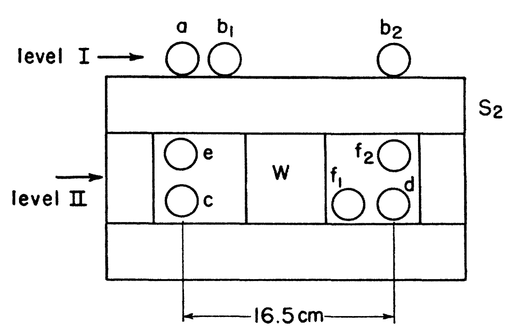

FIG. 3. Arrangement of counters for the detection of simultaneous penetrating particles.

TABLE VI. Ratio of triple and quadruple coincidences for varying wall thickness, and different counter arrangement.

Thickness of wall W (cm)	0	2	5
$N_4\,(a\,b_2\,c\,d)/N_3\,(a\,c\,d)$	0.14	0.20	0.45
$N_4\,(a\,b_1\,c\,d)/N_3\,(a\,c\,d)$			0.10

TABLE VII. Triple coincidences under varying screen thickness.

Thickness of screen S_2 (cm)	1	5	10	15
$N_3\,(c\,d\,e)$	12.1 ± 1.5	3.95 ± 0.25	2.88 ± 0.15	2.74 ± 0.12

TABLE VIII. Ratio of triple and quadruple coincidences with different counter arrangements.

Thickness of S_2 (cm)	1	5	10	15
$N_4\,(c\,d\,e\,f_1)/N_3\,(c\,d\,e)$			0.70	0.50
$N_4\,(c\,d\,e\,f_2)/N_3\,(c\,d\,e)$	0.62	0.40	0.34	0.28

the 2-cm wall), the results can be only considered as an indication of the existence of groups of penetrating particles coming from the air. The role of these particles is only important in the production of coincidences between counters under lead (10 cm) when the counters are not too near to one another (15 cm) and are separated by a wall of a few centimeters of lead. This conclusion is in agreement with the results of Wataghin and others [see bibliography, in Phys. Rev. **59**, 902 (1941)].

(C) Characteristics of the Multiple Secondary Effects in Lead

For this study the counters a and b were removed from level I and placed at level II (counters e and f, Fig. 3). First a series of triple counts ($c\,d\,e$) was made with a wall of 5 cm and a variable screen S_2. Table VII shows that after a very quick decrease, due to the absorption of the air showers, there remains a considerable number of coincidences under as much as 15-cm lead (the wall W being 5 cm thick). Also the increase of the wall from 5 to 10 cm, with a screen S_2 of 15 cm, brought a decrease of N_3 from 2.74 ± 0.12 to 1.56 ± 0.2 showing once again the existence of oblique particles with a strong penetrating power.

A fourth counter was then added which could be placed in two different positions f_1 and f_2. The first one was favorable to the detection of oblique particles; the second one was favorable to the counting of parallel vertical penetrating rays. In each case the number of quadruple coincidences $N_4(c\,d\,e\,f_1)$ and $N_4(c\,d\,e\,f_2)$ was compared to the number of triple counts $N_3(c\,d\,e)$. The thickness of the screen S was increased from 1 cm to 15 cm; the wall W was maintained 5 cm thick. (See Table VIII.) It can be noted that the proportion of quadruples which are due to vertical parallel rays decreases when the screen increases because of the relatively large absorbability of the high energy electrons which are the ordinary cause of the counts. The proportion of quadrupoles is larger when the counter arrangement is favorable to the detection of oblique particles. When the arrangement is suited for the detection of parallel vertical groups of particles the ratio of quadruple to triple counts decreases continuously when the screen S increases. However, the role of these vertical particles is still important with a screen of 10 cm as is shown by following experiments. The shield S being 10 cm thick, and counter f in position f_2, the thickness of the wall W was increased from 5 cm to 10 cm. The ratio N_4/N_3 increased from 0.29 to 0.77. In the last case most of the coincidences were probably due to showers of electrons of high energy from the air and associated with A showers. The high density of tracks in these showers explains the fact that the probability of the quadruple counts is almost as large as that of the triples.

(D) Evidence of the Existence of a Local Production of Penetrating Particles

The preceding experiments suggest that only one part of the coincidences between counters under lead is due to multiple penetrating particles arriving from the air. The other part would have to be attributed to a local production of multiple secondary particles. Some of them are more penetrating than electrons of reasonable energy and can be identified with slow mesons. These particles would diverge from one or from a few centers situated in the lead and their emission could be provoked by a meson or any other incident particles of high energy. The action of the first process would be related to the A showers where beams of very numerous parallel electrons of high energy are present. It would be favored by smaller thicknesses of the screen S, by greater thicknesses of the wall W, by larger horizontal distances between the counters under lead, and by their disposition in vertical telescopes (superposition of two or more parallel counters). The second process would be related to more or less isolated particles of great energy, like mesons. It would be more important with thin walls W, thick screens S, when the counters are arranged at random and are not far from one another. The last section of this paper is devoted to the description of experiments especially devised for the study of this local production of secondary penetrating particles.

EXPERIMENTS ON THE PRODUCTION OF PENETRATING PARTICLES

(A) Counter Experiments

The counters were placed inside a large block of lead (Fig. 4) so that three of them constituted a vertical telescope ($b\,c_1\,d$), the fourth a being separated by a wall of 10 cm. This arrangement is favorable to the detection of groups of vertical particles. Then the middle counter of the telescope c was shifted to c_2 where it was outside of the solid angle determined by b and d, so that at least three vertical particles were necessary for a quadruple count. In each case the triple coincidences $a\,b\,d$ and the quadruples $a\,b\,c\,d$ were registered simultaneously and the values of the ratio N_4/N_3 obtained were found practically equivalent (Table IX). This fact, and also the high value of the ratio N_4/N_3, were confirmed by another measurement where the counter c was placed in position c_3.

TABLE IX. Effect of changed position of counter.

Position of counter c	c_1	c_2	c_3	c_4	c_5
$N_4\,(a\,b\,c\,d)/N_3\,(a\,b\,d)$	0.64	0.77	0.42	0.15	0.08

The counter c was then removed outside of the lead block, first in the immediate neighborhood (c_4) then at a distance of 3 m (c_5). The ratio N_4/N_3 fell to a smaller value in the first case, and to an even smaller one in the second (Table IX). These characteristics fit well with the hypothesis of a local secondary effect, as described above. On the other hand, the interpretation by multiple penetrating rays coming from the air would be difficult. These penetrating particles would have to exhibit two simultaneous properties: (1) A high density of tracks all over the area where the counters are situated, in order to explain the high value of the ratio N_4/N_3 in all positions of counter c inside the lead. (2) A narrow localization in space in order to explain the decrease of the counts when c is displaced outside of the lead.

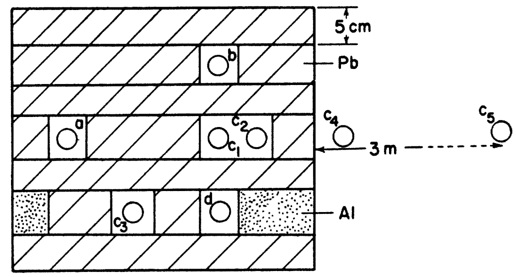

FIG. 4. Detection of local showers of penetrating particles.

This localization has been proved also by the following experiment: Three counters are disposed as $a\,b\,c_1$ in Fig. 4. One of them, a, can be placed at a variable distance from its neighbor c_1(the distances are measured between the centers of the counters) and separated by a wall of 5-cm lead. When the distance between a and c_1 is increased from 10 to 16 cm, all other conditions remaining unchanged, the number of triple counts per hour decreases from 2 ± 0.2 to 1.1 ± 0.1. This could be explained only by a narrow beam of parallel particles or by a spread of particles diverging from a center situated in the neighborhood of the counters.

These two kinds of geometrical groupings of tracks are represented in the cascade showers of electrons as they are generally observed, in air and in the presence of a few masses of dense material. This fact explains why the geometrical properties of the effects in lead here described are strangely similar to those of ordinary showers, with the difference that the medium through which the particles move is air in the one case, lead in the other. An experiment in which the counters were arranged as in Fig. 4 but without any lead surrounding gave a counting rate ten times higher than with all the lead, but the ratio of the quadruple against the triple counts decreased from $N_4(a\,b\,c_1\,d)/N_3(a\,b\,d)=0.53$ to $N_4(a\,b\,c_2\,d)/N_3(a\,b\,d)=0.35$ when counter c was shifted. This ratio decreased again down to 0.12 when the distance of c was increased to a few meters.

(B) Cloud-Chamber Experiments

In order to obtain more direct information about the relation between the counts under lead and the A showers, a vertical cloud chamber was placed sideways in close contact with the lead block containing the three coincidence counters which controlled the expansion. Here the counters were disposed vertically, as shown in Fig. 5 (in horizontal projection); they were separated by at least 5 cm of lead from one another and from the chamber; and a lead plate 10 cm thick covered them. No particle touching two of the counters could penetrate the chamber.

A series of 143 photographs was made with the chamber controlled, and a series of 83 was made at random in order to check the results. After a careful examination of the tracks recorded, the pictures could be classified as follows:

Type of pictures	Number of pictures Controlled	Random
I Shower of more than 3 particles, not much inclined to the vertical	13	0
II One good track, nearly horizontal and crossing the lead block	11	1
One dubious track of the same type	7	7
A pair of tracks of the same type originating from the lead block	3	0
III Two, one, or no tracks of particles of ordinary type, distributed as follows:	109	75
Two tracks	10%	12%
One track	33%	33%
No track	57%	55%

The first type is due to concentrated air showers, probably parts of A showers, and their presence in the controlled photographs is a new evidence of the existence of a penetrating part in these showers.

The frequency of horizontal or of very oblique tracks (type II) is much higher when the chamber is controlled than it is in random operations. These tracks are due mostly to particles issuing from the lead block, and are associated with the secondary processes taking place in the lead and responsible for the controlling coincidence. The number of pictures of types I and II relative to the total of controlled records is in good agreement with the results of the counter experiments

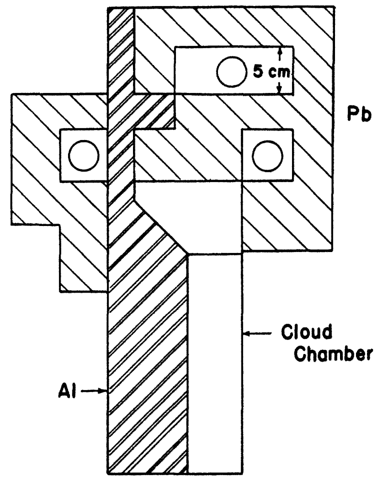

FIG. 5. Arrangement of cloud chamber and controlling counters, in vertical projection.

with counter c in position c_4, (Fig. 4), as given in Table IX. A direct experiment was also made with the chamber removed and replaced by a counter.

The pictures in the third group are identical in aspect and in relative numbers (records with one, two, or no tracks) in both series of controlled and random operations. The tracks recorded have generally nothing to do with the cause of the coincidence, and their number is due to the fact that the resolving power of the cloud chamber is much smaller than that of the counter set. So most of the coincidences between the three counters in the lead block are due to a local phenomenon taking place in the lead and probably caused by a single initial particle.

If the oblique tracks in group II are really due to some of the particles emitted in this local process and which have been able to emerge outside from the lead, it would be interesting to get some information about their nature. The fact that they appear single or in pairs of notable divergence suggests that they are mesons. This hypothesis is in agreement with the penetrating power of some of the oblique particles as measured in the wall W.