Cloud-Chamber Investigation of Charged V Particles*

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An analysis of 84 charged V events obtained during two years of operation of a vertical magnetic cloud-chamber array is presented. The particular features of interest which are studied in detail are the distribution of P^*, the momentum of the charged secondary in the rest system of the primary, and the possible existence of a component of short lifetime (i.e., $\tau<5\times10^{-10}$ sec). The P^* distribution from 19 slow, accurately measurable positive events is shown to imply that the large majority of these events arise from one or more two-body decays from primaries of mass approximately equal to that of the τ meson. One case turns out to be inconsistent with this interpretation, and is presumed to represent a three-body decay. The P^* distribution from 6 slow, accurately measurable negative events is consistent with a single two-body decay having a P^* value of about 200 Mev/c. This suggests the existence of a negative counterpart to the well-known θ^0 particle, though the statistics are much too poor to permit any strong conclusion. The lifetime analysis provides strong evidence for the existence of a negative component of lifetime equal to or less than $(1.3\pm0.6)\times10^{-10}$ sec. The transverse momentum distribution for these short-lived events is shown to suggest a two-body decay with a P^* value of 201 ± 12 Mev/c.

I. INTRODUCTION

THE properties of charged particles, heavier than the π meson, which decay into a single charged secondary have been studied in detail both in magnetic[1–3] and multiple-plate[4,5] cloud chambers and in photographic emulsions.[6] The results from various studies have tended to indicate that there are apparently several different kinds of such particles, the observed relative number of each kind depending upon the experimental geometry used. Up to the present time, evidence for the following decay schemes has been obtained:

(a) $\kappa\rightarrow\mu+?+?$,[6] $m(\kappa)\approx1000m_e$.

(b) $\chi\rightarrow\pi+?$,[6] $m(\chi)\approx1000m_e$.

(c) $K^+\rightarrow\mu^++\nu$,[5] $m(K_\mu^+)=930\pm15m_e$.

(d) $\theta^+\rightarrow\pi^++\pi^0$,[7] $m(\theta^+)=954_{-20}^{+30}m_e$.

(e) $\tau\rightarrow\pi+2\pi^0$,[8] (Alternate decay mode of τ).

(f) $\Sigma^+\rightarrow p+\pi^0$,[1,9,10] $Q=117\pm2$ Mev.

(g) $\Sigma^\pm\rightarrow\pi^\pm+n$,[10] $Q=111\pm2$ Mev.

(h) $\Xi^-\rightarrow\pi^-+\Lambda^0$.[11,12] $Q=66\pm6$ Mev.

Some of the particles listed under different headings above may be identical.

This paper describes an analysis of 84 charged V events observed in a magnetic cloud chamber. A possible interpretation of these events in terms of the above-listed particles is also given. This discussion does not include those few events which are clearly examples of "cascade decays" [category (h) above].

II. EXPERIMENTAL ARRANGEMENT AND MEASUREMENT TECHNIQUE

The data discussed in this paper were obtained with the 48-in. magnet cloud chambers which have been in operation in Pasadena (220 m elevation) since January, 1953. For the first seven months of operation, this equipment consisted of a vertical array of four cloud chambers each 55 cm long, 20 cm high, and 20 cm in illuminated depth, placed in a magnetic field of approximately 8000 gauss. In July, 1953, the two upper chambers were replaced by a single double-size chamber. Expansions were triggered by a penetrating-shower detector consisting of three trays of eight G. M. counters placed above, between, and below the chambers. Each pair of chambers was separated by approximately 50 g/cm² of lead or copper absorber. For most of the work the two coincidence arrangements 2–2–1 (2 or more counts from the upper tray, 2 or more from the middle tray, and 1 or more from the bottom tray) and 0–2–2 were used in parallel, yielding a counting rate of about three per hour. Stereoscopic photographs were taken by two cameras (one for each pair of chambers) on 70-mm Kodak Linagraph Pan film. The experimental arrangement is indicated schematically in Fig. 1.

Considerable care was exercised to minimize convective distortions resulting from unsatisfactory temperature conditions on the chambers. For this purpose an elaborate thermostatting arrangement was used to

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[1] York, Leighton, and Bjornerud, Phys. Rev. **95**, 159 (1954).
[2] Buchanan, Cooper, Millar, and Newth, Phil. Mag. **45**, 1025 (1954).
[3] Kim, Burwell, Huggett, and Thompson, Phys. Rev. **96**, 229 (1954).
[4] Bridge, Peyrou, Rossi, and Safford, Phys. Rev. **90**, 921 (1953).
[5] Gregory, Laguarrigue, Leprince-Ringuet, Muller, and Peyrou, Nuovo cimento **11**, 292 (1954).
[6] Proceedings of the Bagnères Conference, 1953 (unpublished).
[7] Hodson, Ballam, Arnold, Harris, Rau, Reynolds, and Treiman, Phys. Rev. **96**, 1089 (1954).
[8] Crussard, Kaplon, Klarmann, and Noon, Phys. Rev. **93**, 253 (1954).
[9] Castagnoli, Cartini, and Manfredini, Nuovo cimento **12**, 464 (1954).
[10] Proceedings of the Padua Conference, Nuovo cimento **12**, Suppl. No. 2 (1954).
[11] E. W. Cowan, Phys. Rev. **94**, 161 (1954).
[12] W. B. Fretter and E. W. Friesen, Phys. Rev. **96**, 853 (1954).

produce as uniform temperature conditions over the chambers as possible, with the exception of a slight vertical gradient to insure stability. Even so, the magnitude of thermal distortions varied considerably during the experiment. The assignment of errors was made on the assumption (believed to be conservative) that 3 Bev/c was the maximum detectable momentum for tracks of 20 cm length except when the presence of visible distortions required a corresponding increase in the estimated magnitude of the errors.

The measurement and reprojection procedures were essentially scaled up versions of those used by Leighton *et al.*,[13] and have been described in detail by van Lint.[14]

III. GENERAL SURVEY OF THE DATA

Out of approximately 30 000 pictures obtained over two years of operation, a total of 84 analyzable charged V events were obtained. In the identification of these events the transverse momentum of either the primary or the secondary was required to be greater than 50 Mev/c without any visible recoil blob at the apex, to eliminate scatterings and $\pi-\mu$ decays.[1] Table I shows the numbers of positive and negative decays observed in each chamber. The chambers are numbered from top to bottom, and the number 12 is used to refer to the double-size chamber which replaced chambers 1 and 2. In trying to interpret this distribution of decays one should note (see Fig. 1) that on the average one can see with ease about 2 cm closer to the production layer in chambers 2 and 4 than in chambers 12, 1, and 3 because of the location of the cameras. Therefore, any events with mean decay distances comparable to 2 cm will be predominantly found in chambers 2 and 4. Table I shows no indication of any short-lived positive component. In particular, there are about as many positive decays in 1 as in 2, and in 3 as in 4; and chamber 12 shows the large number of decays expected for long-lived particles taking full advantage of the double size of the chamber. On the other hand, there are five times as many negatives in chambers 2 and 4 as there are in chambers 1 and 3. This could be a statistical fluctuation though the probability that 30 events will split in the ratio 25 to 5 or greater if the *a priori* probabilities are equal is only 0.0004. Thus the distribution of the decays among the chambers suggests the presence of a very short-lived negative component.

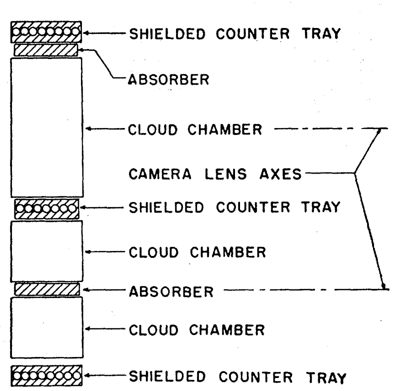

FIG. 1. Schematic diagram of the cloud chamber, absorber, and counter geometry.

TABLE I. Numbers of positive and negative events in various subgroups of the sample analyzed.

Sign	Total number	Distribution in various chambers 12	1	2	3	4	Heavily ionizing
+	41	17	4	4	9	7	19
−	43	13	1	5	4	20	5

The last column of Table I shows the numbers of positive and negative decays with heavily ionizing primaries. Here there appears to be a very large predominance of positives. In fact, if one supposes that this asymmetry arises from a statistical fluctuation, the probability of obtaining from 24 slow events a distribution of equal or greater asymmetry is only 0.006.

From the above considerations, it is clear that although the total numbers of positives and negatives are nearly equal, there appear to be important differences between the two components. These will be treated in more detail in Sec. V where the quantitative aspects of the data are discussed.

IV. THEORETICAL DISCUSSION OF MEASUREMENTS

A. Decay Energies

From each of the observed decay events, an effort was made to secure maximum information concerning the nature and energetics of the decay. The quantity which is studied is P^*, the momentum of the charged secondary in the rest system of the primary. Some information about P^* can be secured from P_T, the transverse momentum of the charged secondary, a quantity independent of the motion of the primary. This transverse momentum is always a lower limit to the value of P^* for each individual decay event, and its distribution $F(P_T)$ is related to the distribution of P^*, $G(P^*)$, by the equation

$$F(P_T)dP_T=\int_{P_T}^{P_{\max}^*}\frac{G(P^*)dP^*}{P^*(P^{*2}-P_T^2)^{\frac{1}{2}}}P_TdP_T,$$

if the decay is isotropic in the rest system.

In particular, a two-body decay will give a P_T distribution which is highly peaked at the high end while a three-body decay will generally give a very much broader distribution with a very flat maximum near the middle.

If the ionization or momentum of the primary can be obtained and used to estimate β, its speed, then the momentum P^* can easily be calculated from the usual

[13] Leighton, Wanlass, and Anderson, Phys. Rev. **89**, 148 (1953).
[14] V. A. J. van Lint, Ph.D. thesis, California Institute of Technology, 1954 (unpublished).

Lorentz transformations. In making these calculations it is necessary to make two assumptions:

(1) The identity of the charged secondary must be assumed.

(2) If the primary momentum is available, one must assume the mass of the primary to get the velocity β.

The errors introduced by these assumptions are easily seen to be proportional to $\cos\theta^*$ (where θ^* is the angle of emission in the rest system) and, hence, are small for cases for which $\cos\theta^*$ is small. Furthermore any average value of P^* which is taken from a number of cases will have small errors from this source since $\langle\cos\theta^*\rangle=0$, i.e., for an isotropic distribution of decays these errors tend to cancel out.

B. Effect of Biases

In attempting to interpret the shape of a distribution (of P^* or P_T for example) in terms of a decay scheme, it is essential to take into account the effects introduced by the biases of the cloud chambers. Because of these biases, events which occur in one part of the distribution may be favored over those which occur elsewhere so that the resulting distribution may depend not only on the decay properties but also on the limitations of observation and measurement introduced by the cloud chamber geometry. It should be noted that such biases exist even if the width of the distribution arises wholly or in part from experimental errors, for in such cases events in which the errors are in one direction may be more easily measured than those for which the error is of opposite sign.

This bias problem may be attacked in two ways:

(1) The range of the variable in the distribution and the sample of events represented can be selected so that a member of this sample would have been included no matter where it had occurred within the allowed range of the variable.

(2) The theoretical distributions can be altered to take account of the cloud chamber biases.

As illustrations of these ideas, consider the P^* and P_T distributions. It will be assumed in this discussion that the three fundamental quantities P^*, θ^*, and β (all previously defined) are independently distributed. The main source of bias in the P^* distribution arises from the fact that for unfavorable locations in the cloud chamber a decay may be measurable only if its value of P^* is not too large. Even if the P^* distribution is actually only a single line, those cases in which errors tend to decrease the measured value of P^* will appear to be more accurately measurable than those events in which the errors increase P^*. On the other hand, very low values of P^* (<100 Mev/c) also tend to be discriminated against because of the likelihood of confusion with $\pi-\mu$ decays or scatterings.

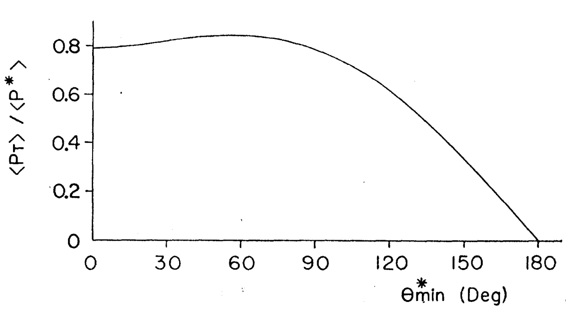

FIG. 2. Plot of the ratio $\langle P_T\rangle/\langle P^*\rangle$ as a function of the angle $\theta_{\min}^*$.

For each event one must therefore assign a range of possible values of P^* such that for any of these values, the event could have been measured with sufficient accuracy and not confused with scatterings or $\pi-\mu$ decays. The upper limit of this range is obtained by requiring that the secondary momentum be measurable to a certain preassigned accuracy. The lower limit is essentially zero for cases with heavily ionizing primaries since these are identifiable as charged V particles regardless of the value of P^*. For events with minimum-ionizing primaries, one can take as the lower limit that value of P^* which would give 50 Mev/c transverse momentum.[1] Having thus assigned a useful range to each event, one should take for the distribution an overall range which is within the limits of most of the cases and over which the shape of the distribution has interest; and one should include in the distribution only those cases whose individual ranges of measurable P^* include the overall range for the distribution. Carrying out such a procedure does not mean that events thereby excluded should be completely disregarded. Such events, however, would tend to be the least accurately measured ones and, by themselves, could not be used to provide very strong evidence without being quite sure that their errors had been properly estimated.

The bias situation in the analysis of the transverse momentum distribution is considerably more complicated. Here the bias arises from the fact that the most easily detectable and measurable events are generally those which are emitted with large backward angles in the center-of-mass system. Such biases are most pronounced for decays which occur in unfavorable locations in the chambers such that the secondary track length is short, and for events with high primary velocity. The effects of such biases are well illustrated in Fig. 2 which shows how the quantity $\langle P_T\rangle/\langle P^*\rangle$ (the symbol $\langle\ \rangle$ stands for mean value) varies as a function of the angle $\theta_{\min}^*$, the minimum angle of decay in the center-of-mass system for which the event would be sufficiently well measurable to be included in the distribution. If one assumes an isotropic angular distribution in the center-of-mass system (as has been done to obtain the curve of Fig. 2), the ratio $\langle P_T\rangle/\langle P^*\rangle$ is purely geometrical, that is, independent of the distribution of P^* except insofar as $\theta_{\min}^*$ depends upon P^*. It is seen from Fig. 2 that for events sufficiently slow and well located that all backward angles give measurable decays (i.e., $\theta_{\min}^*\leq 90°$), the value of $\langle P_T\rangle/\langle P^*\rangle$ remains reasonably constant (sufficiently so to make the

TABLE II. Data on 19 positive events for which an accurate value of P^* can be obtained [P_1=momentum of the primary, $(I/I_0)_1$=ionization of the primary, P_2=momentum of the secondary, $(I/I_0)_2$=ionization of the secondary, θ=angle of decay, $P^*(\mu)$=center-of-mass momentum assuming μ-meson secondary, $P^*(\pi)$=center-of-mass momentum assuming π-meson secondary, ΔP^*=probable error in P^*].

Case	P_1 (Mev/c)	$(I/I_0)_1$	P_2 (Mev/c)	$(I/I_0)_2$	θ deg	$P^*(\mu)$ (Mev/c)	$P^*(\pi)$ (Mev/c)	ΔP^* (Mev/c)
6823	225± 17	3–6	112±10	<2	100	142	150	±11
9538	415± 80	1.5–3	200±40	<2	89	272	282	±55
10 041	630± 90	< 2	270±38	<2	53	242	251	±34
12 010	~50	>30	322±40	<1.5	37	295	295	±40
12 191	251± 75	2.5–4.5	126±23	<2	132	200	211	±41
12 564	600±130	< 1.7	177±14	<2	92	232	262	±39
16 091	473± 55	1.2–2.5	107± 6	...	101	201	222	±17
17 496	545± 54	1.1–1.8	460±70	<1.5	11	184	175	±33
18 571	340± 95	2–4	150±10	1.2–2	97.5	206	214	±23
18 670	218± 15	3–6	204±19	1.1–2	97	240	244	±21
20 445	230± 11	2.5–5	210±20	<2	112.5	274	280	±25
22 644	590±150	< 2	360±55	<2	38	222	222	±31
24 508	370± 76	1.5–3	198±40	<1.5	77	222	229	±44
27 615	330± 90	< 2.5	390±80	...	33	247	240	±55
29 312	164± 15	4–8	329±25	<1.5	26	245	242	±20
30 166	202± 11	3–5	330±25	<1.5	45	259	257	±20
31 855	...	1.5–2.5	285±29	<1.5	41	191	189	±21
33 725	1000±300	< 1.5	300±25	<1.5	38	215	228	±34
37 034	130± 30	3.5–7	206±21	<1.5	90	215	216	±22

distribution useful in distinguishing two- from three-body decays), but that for events for which only large backward angles give measurable decays (i.e., $\theta_{\min}^*>90°$) the value of $\langle P_T\rangle/\langle P^*\rangle$ drops very rapidly, which has precisely the effect of making a two-body distribution look like a three-body one. Therefore, if biases are to be minimized, each event included in the distribution must be sufficiently well located and sufficiently slow that if the secondary had been emitted with the maximum transverse momentum at $\theta^*=90°$, it would have been measurable and the laboratory angle of decay would have been sufficiently large to permit easy detection of the event.

V. DETAILED DISCUSSION OF THE DATA

A. Direct Measurement of P^*

A total of 32 events (25 positive, 7 negative) had measurable secondary momenta, and were heavily ionizing and/or had measurable primary momenta. Two values of P^* were calculated for each of these events assuming a primary mass of 500 Mev and a π- or a μ-meson secondary. It should be noted that in all these cases the measured primary mass either directly suggests or is not inconsistent with a value around $1000m_e$. Ranges of values of P^* for which the event was measurable were also calculated as indicated in Sec. IV, the upper limit of each range being set by requiring a 33% accuracy in the momentum of the secondary. All events (19 positive, 6 negative) which were measurable for 100 Mev/$c<P^*<$300 Mev/c are listed in Tables II (positives) and III (negatives). A histogram of the P^* distribution for the positives is shown in Fig. 3. Only the positives were plotted to represent as pure a sample as possible. The intervals on the histogram were chosen to include roughly equal numbers of cases, and each event was given the same rectangular area with a half-width equal to the assigned error. It is clear from Table II and the histogram that most of the positive events are consistent with a single two-body decay. The spread of the distribution is completely consistent with the error width to be expected from a two-body decay, but is much smaller than would be expected for a three-body decay. The only individual case which appears inconsistent with this interpretation is No. 6823 which will be discussed shortly. If this event is deleted from the sample, the weighted mean value of P^* obtained from the remaining events, on the assumption that they all represent the same two-body decay, is:

$$\langle P^*\rangle = 239\pm 7 \text{ Mev}/c \quad (\mu \text{ secondary}),$$
$$\langle P^*\rangle = 243\pm 7 \text{ Mev}/c \quad (\pi \text{ secondary}),$$

where the error was obtained from the spread of values about the mean combined with a possible 2% error

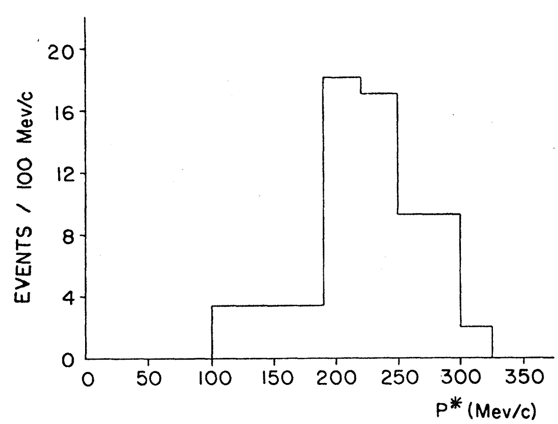

FIG. 3. P^* distribution for 19 accurately measurable positive decay events, calculated on the assumption that the charged secondary is a μ meson and that the primary has a mass of 500 Mev.

TABLE III. Data on six negative events for which an accurate value of P^* can be obtained.

Case	P_1 (Mev/c)	$(I/I_0)_1$	P_2 (Mev/c)	$(I/I_0)_2$	θ deg	$P^*(\mu)$ (Mev/c)	$P^*(\pi)$ (Mev/c)	ΔP^* (Mev/c)
19 648	500 ± 80	<1.5	660 ± 190	<2	23	310	305	± 100
24 018	101 ± 15	10–20	220 ± 55	<2	102	236	238	± 58
26 717	204^{+125}_{-62}	2–4	280 ± 65	1.2–2.5	41.5	198	196	± 45
26 971	1100 ± 280	<1.3	205 ± 16	<2	39	180	203	± 33
34 082	···	1.3–2.5	186 ± 18	<1.5	61.5	188	196	± 27
35 487	300 ± 125	2.5–5	213 ± 5	<1.5	66	198	198	$^{+12}_{-5}$

arising from the calibration of the magnetic field and systematic gas distortions.[15,16]

If one assumes that the two-body decay scheme represented is

$$K^+ \rightarrow \mu^+ + \nu,$$

the above value of P^* corresponds to a primary mass of $980\pm 30 m_e$. This figure is quite consistent with the mass of the τ meson, and is a little higher than, though probably not inconsistent with, the mass of the $K_\mu^+(930\pm 15 m_e)$.

From Table II, it is clear that the errors on individual cases are fairly large and that some of the decays could be of the type[7]

$$\theta^+ \rightarrow \pi^+ + \pi^0 \quad (P^* = 206 \text{ Mev}/c).$$

In fact, some of the cases listed in Table II seem to agree better with this lower value of P^*. It is clear that if a few of these events are actually present, their removal would have the effect of raising somewhat the $\langle P^* \rangle$ of the remaining events, thereby increasing the discrepancy with the value $P^* = 226$ Mev/c now accepted for the K_μ particle. It thus appears quite likely that at least some of the present events have P^* values appreciably above 226 Mev/c.

Event 6823 is not consistent with the values of P^* suggested above, nor does it appear very likely that it represents the decay

$$\tau^+ \rightarrow \pi^+ + 2\pi^0,$$

because its measured value of P^* is nearly two probable errors above the maximum allowed value, itself quite improbable, of 133 Mev/c for this decay. It may, however, represent an example of the decay

$$\kappa^+ \rightarrow \mu^+ + 2 \text{ neutrals},$$

which has been suggested by photographic plate results. It is also quite possible that some of the higher values of P^* which are consistent with the previously discussed two-body decays really arise from the three-body decay suggested above. As has been mentioned before, however, the lack of events with low values of P^* makes it very unlikely that such a three-body decay could, by itself, account for the observed distribution of P^* values.

The negative events of Table III appear to be consistent with a single value of P^* of approximately 200 Mev/c. In particular, the best case (35 487) yields a value, 198_{-5}^{+12} Mev/c, which seems considerably lower than the average given above for the positives, but is highly consistent with the value 206 Mev/c, expected for $\theta^\pm$ decay. The small number of cases of course prevents any strong conclusion regarding the existence of the decay

$$\theta^- \rightarrow \pi^- + \pi^0 \quad (P^* = 206 \text{ Mev}/c),$$

but this must be regarded as a possible interpretation of the data.

It has been suggested by the Massachusetts Institute of Technology multiple-plate chamber results that the positive S particles consist of a mixture of particles undergoing the decays:

$$K_\mu^+ \rightarrow \mu^+ + \nu,$$

$$\theta^+ \rightarrow \pi^+ + \pi^0.$$

One possible interpretation of the positive-negative asymmetry for slow events, consistent with the present data, is that only the θ^+ has a negative counterpart. If this interpretation were correct, it would imply that the K_μ^+ and θ^+ are definitely not alternate decay schemes of the same particle. More data on negative decays would be necessary, however, to establish the correctness of this interpretation.

B. Analysis of Lifetime

The work of York *et al.*[1] and Kim *et al.*[3] has indicated that the charged V particles contain a short-lived component (i.e., $\tau \lesssim 5\times 10^{-10}$ sec). The discussion of Sec. III has suggested that perhaps the events treated in this paper may also contain a short-lived group.

In order to verify the existence of a short-lived component, and to measure its lifetime, it is necessary to study the distribution of decay points in the chambers to ascertain whether these points are more concentrated near the top of the chambers than would be expected

[15] As an indication of the possible magnitude of gas distortions, one can consider the mean Λ^0 Q-value obtained with the same apparatus, namely 36 ± 0.5 Mev. If the difference between this value and the presently accepted 37 Mev (see reference 16) is taken as a significant indication of the direction of such distortions, then a similar effect on the positive charged V data would cause an overestimate in P^* of about 5 Mev/c. This would reduce the P^* value corresponding to a μ-meson secondary down to 234 Mev/c.

[16] Friedlander, Keefe, Menon, and Merlin, Phil. Mag. **45**, 533 (1954).

for a uniform distribution. In particular, one measures the quantities x and D for each event, where x is the decay length and D is the gate length. Both of these distances were measured from a point on the primary track 1 cm from where this track entered the well-illuminated region of the chamber, this latter distance being measured along the projection of the track upon the plane of the chamber piston. Any events for which the decay occurred closer to the edge of the illuminated region were not used. For the purposes of calculating D, the gate length, it was assumed that an event was properly identified as a charged V particle if the transverse momentum was one probable error above 50 Mev/c. No event with decay angle less than 10° was used, on the grounds that the detection efficiency for these was much poorer than for larger-angle cases. Histograms of the x/D distribution for all cases for which $D\geq 8$ cm are shown in Fig. 4 (positives) and Fig. 5 (negatives). The corresponding mean values are:

$$\text{Positives: } \langle x/D\rangle = 0.54\pm 0.05 \text{ (34 cases),}$$

$$\text{Negatives: } \langle x/D\rangle = 0.33\pm 0.05 \text{ (30 cases).}$$

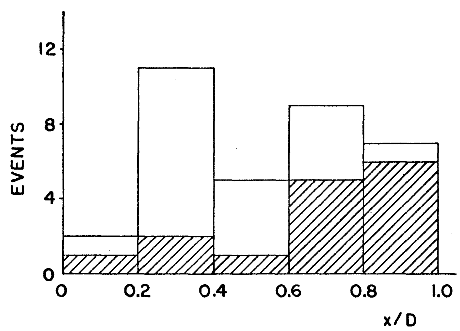

FIG. 4. x/D distribution for 34 positive events. The shaded area represents those cases whose primaries are heavily ionizing.

The errors given above are statistical standard deviations to be expected for 30 cases randomly selected from a population having a uniform x/D distribution.

It appears from the histograms and from the above values of $\langle x/D\rangle$ that the positives exhibit the uniform distribution expected from long-lived decay events while the negatives seem to contain a short-lived component. It should be noted that the evidence concerning the existence of a short-lived component provided by the x/D distribution is completely independent of that afforded by the numbers of events detected in the various chambers. If each of the observed distributions is interpreted as a statistical fluctuation rather than as due to the existence of a short-lived component, the probability of getting such a combination of fluctuations is extremely small.

Further support for the above conclusions is afforded by a study of the distribution of the origins from which the charged V particles come. Figure 6 shows a plot of the values of x/D *versus* Δ for those events which have origins less than 10 cm from the illuminated region of the chambers. Δ is the distance between an origin and the illuminated region. The two vertical lines on the plot are the limits determined by the cloud-chamber geometry within which most of the events are likely to have their origins. The following features can be seen:

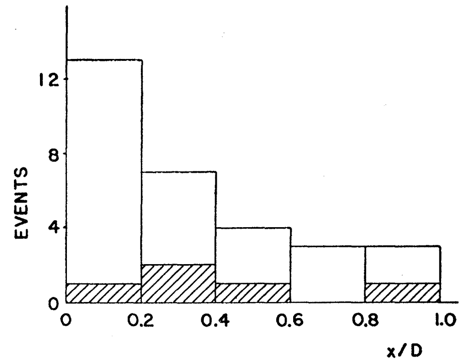

FIG. 5. x/D distribution for 30 negative events. The shaded area represents those cases whose primaries are heavily ionizing.

(1) The positives are distributed in approximately uniform fashion with no apparent correlation between x/D and Δ.

(2) The negatives, on the other hand, seem to be concentrated near the lower limit of Δ. Furthermore, the low values of x/D appear to be associated with close origins.

The observations provide additional evidence in favor of the interpretation of the low value of $\langle x/D\rangle$ of the negatives as due to a short-lived component (i.e., $\tau<5\times 10^{-10}$ sec). It should be noted, on the other hand, that it is very unlikely that a short-lived component is the sole constituent of the negative charged V particles, for the following reasons:

(1) Event 24 018 (see Table III) has a lifetime within the illuminated region of the chamber of about 2×10^{-9} second. Event 19 648 traverses two chambers prior to decay and thus lives about 3×10^{-9} second. Such events are almost certainly not of the same type as the short-lived events discussed above.

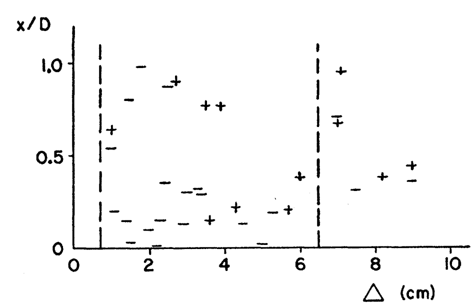

FIG. 6. Relationship between x/D and Δ (the distance from the edge of the illuminated region to the interaction in which the primary is produced) for 12 positives and 21 negatives. The two vertical dashed lines represent the approximate boundaries of the absorber between chambers and are, therefore, expected to enclose most of the events. Only those cases for which $\Delta\leq 10$ cm are plotted.

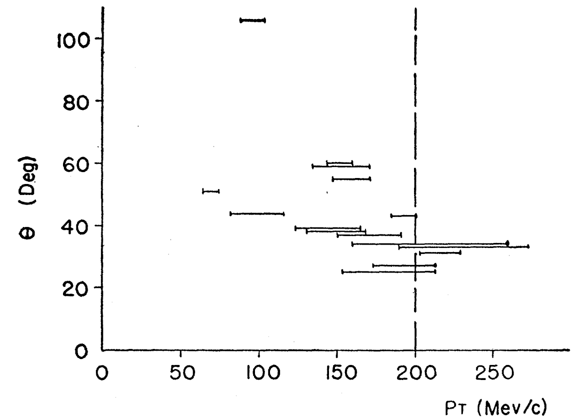

FIG. 7. Relationship between transverse momentum P_T and laboratory angle of decay θ for 15 "short-lived" negative events. The vertical dashed line represents the calculated value of $\langle P^*\rangle$ for these events.

(2) There appears to be no correlation between slow primaries and very short decay distances. This is shown clearly in Fig. 5 where the cross-hatched region represents the five slow cases. It is apparent that these events have much longer mean lives than do those which are responsible for the peaking of the x/D distributions at the low end.

C. Further Properties of the Short-Lived Events

It is clear that for short-lived events, long secondary track lengths are in general available, and hence one can hope to obtain a reasonably unbiased transverse momentum distribution for them. In order to obtain such a distribution a sample consisting only of negative events for which $x\leq 4$ cm or for which the primary track length was too short to calculate a value of x, and which were not heavily ionizing, was chosen. Fifteen cases satisfied the above requirements (which, incidentally, would have been satisfied by only one positive). If the previous interpretation of the lifetime data in terms of a short-lived negative component is correct, then one can reasonably expect that the above mode of selection will give a sample consisting chiefly of the short-lived events, and conclusions drawn from this sample should be applicable to the short-lived component. On the other hand, if the x/D distribution does in fact represent a fluctuation, the selection procedure will in no way bias the transverse momentum distribution, and the conclusions drawn from it will apply to the total sample of negative charged V particles.

In order to examine the effect of biases (discussed in Sec. IV) on the transverse momentum distribution, the velocities of the primaries must be estimated. For this purpose, a plot of laboratory angle of decay *versus* transverse momentum was made. This is shown in Fig. 7. For each event the error in the transverse momentum is shown. An examination of this plot reveals that, except for the two events with the lowest angles, the higher transverse momenta are associated with the lower angles.

This observation is clear evidence that most of the secondaries are emitted *backward in the center-of-mass system*, with the probable exception of two or three events. An estimate of the speed of the primaries in these events can be made from the fact that the maximum transverse momenta of about 200 Mev/c are associated with laboratory angles of about 30°. From these numbers one obtains $\gamma\beta\approx 1.4$. If one then plots a transverse momentum distribution for only those members of the sample which satisfy the bias requirements of Sec. IV, assuming $\gamma\beta\approx 1.4$ for all cases, the plot of Fig. 8 results. (The application of these bias requirements eliminates only one case from the sample because the selection of short-lived events favors long secondary track lengths.) Figure 8 appears most consistent with a two-body decay. If such a decay is assumed, with a value of $P^*\approx 200$ Mev/c as indicated by the figure, one can compute a more precise value of P^* in the following way:

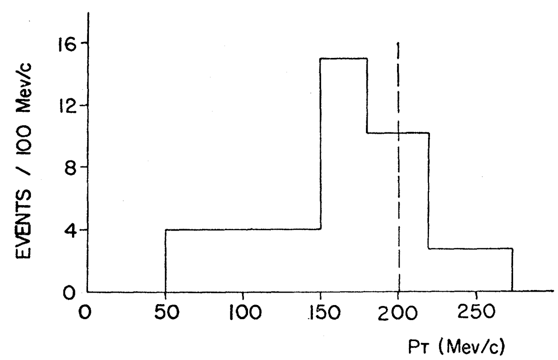

FIG. 8. Transverse momentum distribution for 14 "short-lived" negative events. The dashed line represents the calculated value of $\langle P^*\rangle$ for these events.

(1) Using the plot of Fig. 7 to determine whether the secondary was emitted forward or backward in the center-of-mass system, and assuming $P^*\approx 200$ Mev/c, one calculates a value of $\gamma\beta$ appropriate for each event.

(2) By requiring a minimum laboratory angle of 10° and a minimum accuracy in the secondary momentum of 25%, one next determines the value of $\theta_{\min}^*$, the minimum angle in the center-of-mass system for which each decay can be considered as detectable and measurable. One then uses Fig. 2 to assign to each case an appropriate value of $\langle P^*\rangle/\langle P_T\rangle$.

(3) Finally, these values averaged over all the events give the best ratio of $\langle P^*\rangle/\langle P_T\rangle$ for the whole sample, from which $\langle P^*\rangle$ can be calculated from $\langle P_T\rangle$.

The value $\langle P^*\rangle$ obtained by this procedure is

$$\langle P^*\rangle = 201\pm 12 \text{ Mev}/c,$$

where the quoted error combines the probable errors due to statistics and to measurement inaccuracies. The above value also contains a slight correction for the fact that transverse momenta below 50 Mev/c are not included. The value of $\langle P^*\rangle$ just stated is in good agreement with the maximum values of P_T on individual cases, within the measurement errors.

It is clear, from the above result, that the short-lived component of the negative charged V particles is indistinguishable from the longer-lived negative component insofar as decay energies are concerned. Thus, if the primaries of the short-lived decays are K particles, they could represent the negative counterpart of the θ^0:

$$\theta^- \rightarrow \pi^- + \pi^0 \quad (P^* = 206 \text{ Mev}/c).$$

However, it is also quite possible that the primaries are hyperons decaying according to the scheme:

$$Y^- \rightarrow \pi^- + n.$$

The Q value for this decay would then be

$$Q = 125 \pm 12 \text{ Mev}.$$

This is in good agreement with the photographic plate results on the decay:

$$\Sigma^+ \rightarrow \pi^0 + p \quad (Q = 117 \pm 2 \text{ Mev}),$$
$$\Sigma^\pm \rightarrow \pi^\pm + n \quad (Q = 111 \pm 2 \text{ Mev}).$$

If, in fact, the hyperon interpretation is correct, one may then wonder why the positively charged counterparts of these events are not observed. One possible explanation could be that the Σ^+ particle decays predominantly into a proton (rather than a neutron) in which case with the velocities observed for the negative events, the maximum angle of decay would be expected to be around 9°. Such decays would be difficult to detect, particularly in view of the short life of the primary.

D. Lifetime Calculation

The low value of $\langle x/D\rangle$ obtained for the negatives makes a lifetime calculation for these cases possible, but as pointed out in Sec. V-B, the result of such a calculation is likely to be no more than an upper limit to the true lifetime of the short-lived events. In order to make this upper limit as close as possible to the actual value, the following ways of eliminating long-lived events, without introducing biases into the sample, were used:

(1) Only negative decays occurring in chambers 2 and 4 were included in the sample.

(2) No event with a heavily ionizing primary was included.

(3) No event whose primary could be seen in a chamber above the one where the decay took place was included.

Seventeen events fulfilled all the necessary requirements for inclusion in the sample. The speeds of the primaries of these events, necessary for the calculation of the decay times and gate times, were estimated by assuming a unique P^* value of 200 Mev/c for each decay. For those cases for which the secondary momentum was unmeasurable, the primary speed was calculated on the assumption of emission at 90° in the center-of-mass system with a P^* value of 200 Mev/c. It has been shown that this P^* of 200 Mev/c is consistent with both long-lived and short-lived negative events and, hence, can be expected to lead to reasonable estimates of the primary speeds even if the sample contains a mixture of both kinds of events.

The usual maximum-likehood procedure[17] yielded the lifetime

$$\tau = (1.3 \pm 0.6) \times 10^{-10} \text{ sec},$$

where the above error combines the statistical uncertainty with an estimated 50% error in the primary speeds. As mentioned earlier, this value is probably an upper limit to the true lifetime of the short-lived negative events.

VI. CONCLUSIONS

The following conclusions can be drawn from the present data:

(1) Among the slow, long-lived particles there appears to be a considerable positive excess, implying either the existence of a positive particle without negative counterpart, or a strong charge dependence of the production cross section.

(2) The slow, long-lived particles are all consistent with a mass of about $1000m_e$.

(3) The P^* distribution of the positive K particles indicates the presence of at least one two-body decay with a value of P^* consistent with that to be expected from the decay

$$K^+ \rightarrow \mu^+ + \nu,$$

with

$$m(K^+) \sim 950\text{–}1000m_e.$$

There is in addition one good case inconsistent with the above decay scheme which may be interpreted in terms of the scheme

$$\kappa^+ \rightarrow \mu^+ + 2 \text{ neutrals}.$$

(4) The P^* distribution of the negative K particles, though lacking in statistics, suggests that these may all be consistent with the scheme:

$$\theta^- \rightarrow \pi^- + \pi^0.$$

(5) There is evidence for a very short-lived ($\tau \sim 10^{-10}$ sec) negative component which appears to decay into two secondaries with a value of P^* equal to 201 ± 12 Mev/c.

ACKNOWLEDGMENTS

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[17] M. S. Bartlett, Phil. Mag. 44, 249 (1953).