Decay of τ Mesons of Known Charge*†

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The experimental data on the 3π decay of τ mesons is summarized on a convenient two-dimensional plot, both (a) when the π-meson charges are known and (b) when they are not. Some events may be included in plot (a) only if the parent τ meson is assumed positive and arguments supporting this identification for τ mesons decaying in an emulsion are discussed. The dependence of this plot on the τ-meson spin (j) and parity (w) is discussed in general terms and those features depending particularly on w and on its relation with j are emphasized—for example, if the density of events does not vanish at the bottom of the plot, the τ meson must have odd parity and even spin. Simple estimates of the distribution, using only the lowest allowable angular momenta and a "short range" approximation, may be modified by final-state meson-meson attractions, whose effects are discussed qualitatively. The available data are insufficient for any strong conclusion to be drawn but rather suggest even spin and odd parity for the τ meson; the need for careful assessment of geometrical bias in the selection of experimental material is stressed.

1. INTRODUCTION

In a previous paper,[1] the analysis of τ-meson decay events which give rise to three charged π-meson secondaries has been discussed. In this analysis it was generally assumed that the charges of the outgoing π mesons were not known; at that time the data available consisted of events in which the emitted π mesons generally escaped from the emulsion before coming to rest. However, it was emphasized in this work that the identification of the π meson which has charge opposite to that of the parent τ meson would enable a more complete analysis of the distribution of decay configurations and would give a more sensitive indication of specific τ-meson properties such as spin and parity.

Recently, as a result of the widespread adoption of the "stripped emulsion" technique, a number of τ-meson decay events have been reported[2–5] in which the unlike π meson (charge opposite to the parent τ meson) could be identified. In the block of emulsion, the product π mesons may be followed from layer to layer, the probability that a π meson comes to rest before escaping is correspondingly increased, and the sign of charge of each π meson which stops may be established as positive or negative according as it undergoes π-μ decay or not at the end of its range. In one case[3] the geometry of the event was such that all three π mesons could be identified in this way. Further, there have been reported[6] two τ-decay events which were observed in a cloud chamber with a magnetic field present, and for which the π-meson charges were all established.

In several of the emulsion examples, the π mesons identified have been sufficient to establish the sign of charge of the parent τ meson, since its magnitude is known to be $|e|$, and in each case the τ-meson charge has been positive. There are good reasons to suppose that all τ mesons which decay to three π mesons in an emulsion are of positive charge. The statistics of the sign of charge of the identified secondary π mesons also suggests that the parent τ mesons are at least predominantly positive (to the present seventeen π^+ mesons have been identified, compared with nine π^- mesons). The fact that the three π mesons emitted are coplanar (to better than 1° in the most complete decay examples) and, to a less significant extent, the fact that the vector sum of the π-meson momenta is zero to a good accuracy, indicate that at the moment of decay the τ meson had a very small momentum. Now the lifetime of the τ meson is known to be sufficiently long ($\gtrsim 10^{-9}$ sec) for a τ^- meson to come to rest in the emulsion, to be captured into an atom of the emulsion and, by successive Auger processes, to be captured into a low-lying Bohr orbit of the atom. At the time of decay the τ^- meson would then have a considerable velocity and, because of its large mass, a high momentum (of order $(ZM_\tau c)/137n$, Z being the nuclear charge, M_τ the τ-meson mass and n the principal quantum number of the Bohr orbit). The coplanarity of the 3π decay is particularly sensitive to the τ-meson velocity at the time of decay and even a velocity of order $c/137$ would upset the coplanarity by $\sim 3°$ on the average. The τ^+ meson, on the other hand, would move only with thermal velocities after being slowed down by the emulsion and strict coplanarity of the product mesons would be expected. Although it is not possible to argue

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[1] R. H. Dalitz, Phil. Mag. **44**, 1068 (1953).

[2] Lal, Pal, and Peters, Phys. Rev. **92**, 438 (1953). These events are denoted by prefix *B*.

[3] Belliboni, Sechi, and Zorn, Nuovo cimento (to be published). This is event *PAD3* of Fig. 3.

[4] Bristol group, events prefixed by *BR* (private communication).

[5] H. Yagoda, event *Y1* (private communication); M. F. Kaplon, event *R2* (private communication).

[6] R. B. Leighton and S. D. Wanlass, Phys. Rev. **86**, 426 (1952); V. A. J. Van Lint and G. H. Trilling, Phys. Rev. **92**, 1089 (1953).

in this way that particular cases are examples of τ^+ rather than τ^- mesons, statistically the conclusion is again that the majority of τ mesons observed to decay in emulsions are of positive charge.

It is known that there exists some strong interaction involving τ mesons and nucleons, since τ mesons are produced directly in high-energy nuclear interactions. However, this interaction need not necessarily permit the direct absorption of τ mesons by nuclei, since it may well be a τ-meson pair interaction or one connecting the τ meson with some other heavy meson. It is therefore of interest to emphasize that the nuclear absorption of heavy mesons does not require a strong direct interaction between nucleons and heavy mesons, because of the small probability per unit time for the heavy meson decay. Whether a τ meson in an atomic K orbit is absorbed or decays may depend on the competition of a weak nuclear interaction with this slow rate of decay. Even if, for example, it is supposed that the only direct interaction of the τ meson with nucleons is that occurring in virtue of the τ-meson decay scheme, i.e.,

$$\tau^- + P \rightarrow \pi^+ + \pi^- + \pi^- + P \rightarrow \pi^- + P$$
or
$$\rightarrow \pi^+ + \pi^- + N, \tag{1.1}$$

then a τ^- meson in an atomic K orbit of the heavier elements (Ag, Br) of the emulsion will certainly undergo nuclear capture[7] rather than decay. About 30 percent of the τ^- mesons will be captured into atoms of the lighter elements (C,N,O) of the emulsion and these will reach the K orbit before decay; for these τ mesons, nuclear capture will then be, at the least, strongly competitive with decay, even if (1.1) is the only absorptive mechanism effective. It is also to be expected that about 5 percent of the τ^- mesons will be captured into the hydrogen of the emulsion, but most of these will be transferred from the hydrogen to atoms of higher Z (in a time $\sim 10^{-11}$ sec) as a result of the diffusion of the neutral $H-\tau^-$ complex. It is therefore plausible, even in the absence of detailed knowledge of the τ-meson production process, to suppose that the majority of negative τ mesons[8] undergo nuclear capture in an emulsion rather than decay. In the analysis of the data (Sec. 3) it will be assumed that a τ meson observed to decay in an emulsion had positive charge; any corrections due to negative τ-mesons decaying in outer atomic orbits or to τ mesons decaying in flight in the emulsions will clearly be quite small.

The importance of establishing the existence of the alternative decay mode $\tau^{\pm} \rightarrow \pi^{\pm} + \pi^0 + \pi^0$ has been emphasized recently.[9] Some events which may be interpreted as examples of this mode of decay have now been observed.[10] It is of course very difficult to establish definitely for any particular event that it represents this mode of decay rather than, for example, $\tau^{\pm} \rightarrow \pi^{\pm} + 2\gamma$. However, the former hypothesis does not involve any essentially new decay modes and is therefore a very reasonable assumption at the present stage. In this decay only the energy of the charged meson is known and the distribution of this energy will give considerable information on the consistency of this hypothesis and on the nature of the parent meson. The relation between this distribution and that for the π^--meson in τ^+-decay will not in general be unique and a comparison between these would be of considerable interest.

The purpose of the present paper, then, is to discuss briefly the analysis of the decay of the τ^+ meson into three π mesons of known charge and to emphasize some uncertainties in the possible interpretation resulting from the possibility of bias in the selection of experimental material and to the inadequacies of any proposed theory.

2. THE ANGULAR CORRELATION IN τ-MESON DECAY||

The decay of a τ^+ meson, initially at rest, into three π mesons is specified uniquely by the momentum $\mathbf{p}$ of the π^- (unlike) meson and by the momenta $\pm\mathbf{q}/2$ of the π^+ (like) mesons in the center-of-mass system for the two like mesons. As in Fig. 1 the like mesons will be specified, where necessary, by suffices 1, 2, the unlike meson by suffix 3. The magnitudes of $\mathbf{p}$ and $\mathbf{q}$ are related by the conditions of conservation of energy and momentum. The quantity $(\epsilon_1+\epsilon_2)^2-(\mathbf{p}_1+\mathbf{p}_2)^2$ is a Lorentz invariant (units being chosen such that $c=1$; ϵ_i, $\mathbf{p}_i$ are the total energy and momentum of meson i), having the value

$$(M_\tau-\epsilon_3)^2-p^2=M_\tau^2+m_\pi^2-2m_\tau\epsilon_3$$

[7] If the coupling constant between τ-meson and π-meson fields is g, the decay probability per unit time is

$$\sim g^2(M_\tau-3m_\pi)^2c^4\hbar/192\pi^2\sqrt{3}M_\tau.$$

The capture rate from the K orbit of a nucleus of charge Z, resulting from the process $\tau^-+P\rightarrow\pi^-+P$ of (1.1) is

$$\sim G^2(M_\tau{}^3c^4/\hbar^3)(e^2/\hbar c)^3Z^4/8\pi^2,$$

where G, the coupling constant for this process, is expected to be $\lambda g(g_\pi{}^2/\hbar c)(\hbar^2/M)$, g_π being the π-meson nucleon coupling constant, M the nucleon mass, and λ a constant of order 1. This capture rate is equal to the decay rate for $Z\sim 3$. Any other capture processes will contribute to increase this capture rate. For higher τ-meson spin values, the matrix element will be energy dependent, but generally speaking, this will increase the ratio of capture rate to decay rate since higher momenta are concerned in the capture process. It should be remarked here that it appears probable theoretically that nuclear absorption will in fact be effected by some strong interaction of the type $\tau^-+P\rightarrow\pi^0+\Lambda_0$.

[8] It should be noted here that there is no doubt concerning the existence of the negative τ meson since the τ meson observed by Van Lint and Trilling (reference 6) in a cloud chamber was of negative charge.

[9] R. H. Dalitz, Proc. Phys. Soc. (London) **A66**, 710 (1953).

[10] Crussard, Kaplon, Klarmann, and Noon, Phys. Rev. **93**, 253 (1954); P. Barrett (private communication).

|| In this section we shall refer specifically to the decay of τ^+ mesons since it is very probable that the emulsion events exemplify this case. For the description of τ^--meson decay it is only necessary to reverse the sign of all charges, assuming the principle of charge symmetry to be valid.

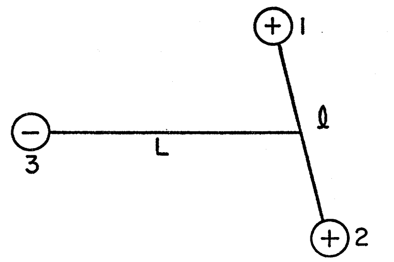

FIG. 1. A τ-meson decay configuration.

in the τ-meson rest system and the value $4m_\pi^2+q^2$ in the c.m. system of the like mesons. Hence,

$$q^2=M_\tau^2-3m_\pi^2-2M_\tau(m_\pi^2+p^2)^{\frac{1}{2}}, \tag{2.1}$$

M_τ, m_π being the masses of the τ meson and π meson, respectively, and $M_\tau=3m_\pi+E$, where E is the kinetic energy released in the decay.

For a τ meson of spin j and parity w, the form of the matrix element describing the 3π-decay from a τ-meson state of magnetic quantum number m may be written generally as

$$T_m(\mathbf{p},\mathbf{q})=\sum_{Llm_Lm_l} C(Llj;m_Lm_l) \times Y_L^{m_L}(\theta_{\mathrm{p}},\phi_{\mathrm{p}})Y_l^{m_l}(\theta_{\mathrm{q}},\phi_{\mathrm{q}})f_{L,l}(p^2,q^2), \tag{2.2}$$

where l is the angular momentum of the like mesons in their rest system and L is the angular momentum of the unlike meson in the τ-meson rest system. Owing to the Bose statistics for the like π^+ mesons, this matrix element must remain unchanged when the coordinates of mesons 1, 2 are interchanged, i.e., when $\mathbf{q}\rightarrow-\mathbf{q}$. This requires l to be even; $l=0,\ 2,\ 4\cdots$. The condition for parity conservation is then

$$w=(-1)^3(-1)^L, \tag{2.3}$$

so that L is confined to odd or even values according as the τ-meson parity is even or odd, respectively. The conservation of angular momentum $\mathbf{j}=\mathbf{L}+\mathbf{l}$ is insured by the properties of the Clebsch-Gordan coefficient $C(Llj;m_Lm_l)$. The probability of the configuration $\mathbf{p}$, $\mathbf{q}$ is proportional to the average[12]

$$\Sigma=\{\textstyle\sum_m[T_m(\mathbf{p},\mathbf{q})]^*[T_m(\mathbf{p},\mathbf{q})]\}/(2j+1). \tag{2.4}$$

This quantity is rotationally invariant and is therefore a function only of p^2 (since q^2 is given by (2.1)) and of θ, where $\cos\theta=(\mathbf{p}\cdot\mathbf{q})/pq$.

It is important to note the lowest values of L and of l possible for given (j,w) since for small p or q, it is reasonable to expect the behavior of (2.2) to be dominated by the term with the lowest value of L or l, respectively. For odd parity w, the allowed L are even. If j is even and w odd, the lowest values of L, l which may occur (not necessarily associated together) in (2.2) are $L=0$ and $l=0$. If j is odd and w odd, L and l are confined to even values and the equation $\mathbf{j}=\mathbf{l}+\mathbf{L}$ cannot be satisfied if either $L=0$ or $l=0$; the lowest allowed values are $L=2$ and $l=2$. For even parity w, the allowed L are odd. If j is odd and w even, the lowest values are $L=1$ and $\mathbf{l}=0$. For even j and even w, the equation $\mathbf{j}=\mathbf{l}+\mathbf{L}$ cannot be satisfied with $l=0$, and the lowest values are $L=1$ and $l=2$. For the τ meson one may hope to distinguish at least between these four possibilities, i.e., between (even j, odd w), (odd j, odd w), (odd j, even w), (even j, even w), from qualitative features of the decay data, as will be discussed later. It is of interest to note that, if the τ meson belongs to the second or fourth class, a competitive 2π decay of the τ meson would be forbidden since this requires $w=(-1)^j$.

The matrix elements used previously[1] for some particular values of (j,w) may be obtained from (2.2) by retaining only those terms corresponding to the lowest possible pairs of angular momenta (L,l) and supposing that the functional form of f_{Ll} is $c_{Ll}p^Lq^l$, where c_{Ll} is a constant. This approximation supposes that the momentum variation of the matrix element is governed essentially by the penetration of the centrifugal barrier, the internal conditions being assumed to vary only slowly with the magnitude of the momentum. In general this approximation may be expected to be a reasonable one when the meson wavelengths are long relative to the "size" of the τ meson; however it is difficult to estimate quantitatively its region of validity and exceptional cases may well be relevant. For very many of the low j values, this approximation leads to a unique expression for the matrix element: for spin values $j\leqslant 5$, there are never more than three combinations of (L,l) possible. Thus, for example, for spin 5 and even parity, the (L,l) pairs relevant are (5,0), (3,2), and (1,4).

At the present stage a nonrelativistic description will be sufficient since the kinetic energy of an emitted π meson cannot exceed $(M_\tau-3m_\pi)(M_\tau+m_\pi)/2M_\tau$ which is close to 50 Mev, and the errors following from this simplification will not affect the general features found. A convenient two-dimensional representation for τ-meson decay events may then be defined in the following way: relative to an equilateral triangle YUV (Fig. 2), a decay event may be specified by the point P such that the perpendiculars (PL,PM,PN) are proportional to the meson kinetic energies (t_1,t_2,t_3) where PN refers specifically to the unlike meson. P depends essentially on the ratios of the squares of the meson momenta, which may be obtained most readily from the angles between the tracks of the outgoing mesons. Since the mesons (1,2) are indistinguishable, the decay event may be represented equally by P or by its reflection in the altitude YDC, so that one need

[12] A general form may be given for this sum, using the techniques of Racah:

$$\Sigma=\sum_{LL'll'K} Y_K^0(\theta)\left[\frac{(2L+1)(2L'+1)(2l+1)(2l'+1)}{(2K+1)}\right]^{\frac{1}{2}} \times(LL'00/LL'K0)(ll'00/ll'K0)W(lLl'L';jK)\mathrm{R.P.}(f_{lL}{}^*f_{l'L'}).$$

consider only that ordering of (t_1,t_2) for which P lies to the right of YDC. In the previous work, it has been shown that momentum conservation requires that P lie within the circle inscribed to the triangle YUV. The Cartesian coordinates (x,y) of P with respect to the axes OX, OY are given by

$$x=(t_1-t_2)\sqrt{3}/E, \quad y=(2t_3-t_1-t_2)/E, \qquad (2.5)$$

when the radius of the inscribed circle is taken to be unity. If numerical factors and relativistic effects are neglected, the density of states is

$$\delta(t_1+t_2+t_3-E)dt_1dt_2dt_3=dxdyE^2/6\sqrt{3},$$

so that variations in the density of events in the semicircle $DABC$ can reflect only the behavior of the probability function. Now PN is proportional to p^2, while PQ is proportional to q^2. The value of $\cos\theta$ associated with P is given by the ratio $x/(GH)$, so that events with constant $\cos\theta$ lie on an ellipse with DC as major axis. Points on the diameter DOC correspond to events with $\theta=\pi/2$, and points on the semicircular boundary correspond to events with $\theta=0$, i.e., to a decay in which the π mesons are collinear. An angular correlation between $\mathbf{p}$ and $\mathbf{q}$ is therefore reflected by a variation of the density of events across the semicircle at any level. If the assumption that only the lowest pairs (L,l) possible contribute singificantly is tenable, such an angular correlation will give very direct indications concerning the spin and parity values possible for the τ meson.

A direct and rather reliable indication concerning the parity of the τ meson may be obtained from a study of the events in the lower part of the semicircle. Here the density of events, averaged along lines parallel to OX, should vary with PN in a way depending on the least L possible, since the unlike meson wavelength is $\gtrsim 0.5\times 10^{-12}$ cm for a meson energy $\leqslant 10$ Mev, and the next allowed L is two units larger. The average density of events may be expected therefore to rise roughly with the Lth power of PN. According to (2.3) the τ-meson parity is then $(-1)^{L+1}$ and there are some limitations

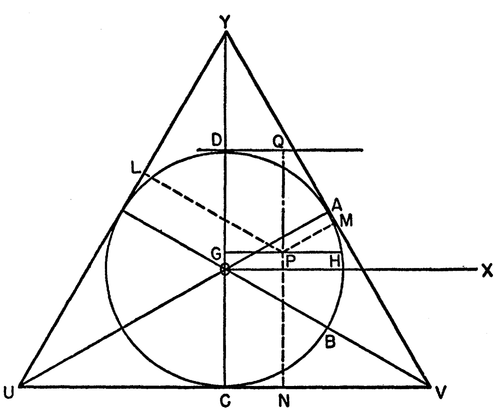

FIG. 2. A triangular diagram for the representation of τ-meson decay events.

on the corresponding j value. The distribution near the upper part of the semicircle may similarly give an indication of the least l—however it will be pointed out shortly that any strong meson-meson attraction which may exist in the $T=2$ two-meson state would distort the distribution in this region. One further specific conclusion may be stated, that, for $w=(-1)^j$, the density of events must vanish on the semicircular boundary. This may be seen from the fact that, for $w=(-1)^j$, all tensors of rank j formed in (2.2) from tensors of rank L and l must contain a factor $\mathbf{p}\times\mathbf{q}$; alternatively it follows from the fact that $C(Llj;00)=0$ for l even and $(j+L)$ odd.

When the charges of the emitted π mesons are not known, it can only be said that the corresponding point is one of three, P itself or its reflections in the altitudes OA and OB. Consequently, in the previous work,[1] the representation of τ-meson events was confined to the area AOB. This diagram, which here corresponds to giving up knowledge of the meson charges, may be obtained from the diagram above by folding DOA and BOC across OA and OB, respectively, and summing the three densities arriving on point P.

For the decay process $\tau^+\rightarrow\pi^++2\pi^0$, only the quantity p^2 is observable and the distribution of this (i.e., the energy of the charged meson) is obtained by integrating the two-dimensional plot $DABC$ perpendicular to DOC, i.e., by averaging over $\cos\theta$. In a similar way to that described above a strong indication of the τ-meson parity may be obtained from the behavior of this distribution at the low-energy end.

If there exist strong interactions between the emitted π meson, the assumption that only the lowest angular momenta are significant will certainly be inadequate in some parts of the diagram. However, it has been pointed out by Brueckner and Watson[13] for the process $p+p\rightarrow n+p+\pi^+$ and by Stuart and Watson[14] for the process $\pi^-+d\rightarrow n+n+\gamma$ that the short-range interactions between the final nucleons may greatly modify the angular and energy distributions of the products although playing no important part in the primary mechanism of the reaction. For these cases it has been found possible to separate the processes into two stages, the primary mechanism and the final-state interaction, which may be discussed consecutively. If this separation is possible in the case of τ-meson decay, the meson-meson final-state interaction may be taken account of most simply by extracting from the matrix element (2.2) a factor $\prod(a_{ij})$, where a_{ij} is the scattering amplitude for the mutual scattering of mesons i, j with the relative momentum appropriate to the configuration considered and the product goes over all meson pairs. The remaining part of the matrix element, describing the primary mechanism, may then be expected to contain mainly terms corresponding to low angular momentum. The relative momentum K_{ij} of mesons

[13] K. Brueckner and K. M. Watson, Phys. Rev. 87, 621 (1952).
[14] K. M. Watson and R. N. Stuart, Phys. Rev. 82, 738 (1951).

i, j may be expressed in terms of the kinetic energy of the third meson k according to an expression similar to (2.1),

$$K_{ij}^2 = (M_\tau - 3m_\pi)(M_\tau + m_\pi) - 2M_\tau t_k. \qquad (2.6)$$

In general the final-state interaction effect may be expected to be large for small relative momentum of two mesons, in which case, according to (2.6), the third meson has energy close to the maximum allowed energy. In the diagram of Fig. 2, meson-meson attraction effects may greatly increase the density of events close to point A or to point C, depending on the isotopic-spin dependence of this interaction. For the decay of the τ meson into three charged mesons, an increase in the density of events near to A is to be expected only if there is a strong attraction in a two-meson state of total isotopic spin $T=2$, whereas an increase in the region of C may result from attraction in states $T=0$ or 2. If the matrix element is antisymmetric in (1,3) in the region near to C, as would be the case if the mesons (1,3) are predominantly in a $T=1$ state, the unmodified density of events would be zero at C and small in this neighborhood. A strong $T=1$ meson-meson interaction would not then give a peak in this region although it would greatly increase the density over that of the unmodified theory: an example of this case is that of the vector τ meson discussed previously for the case of nonidentified charges.

3. THE EXPERIMENTAL DATA

To the present, twenty-nine τ-meson decay events have been reported, as well as three events which may possibly represent $\tau^+ \rightarrow \pi^+ + 2\pi^0$ decay. Of the former, a complete analysis is possible for the two events observed in cloud chambers in the presence of a magnetic field and for three emulsion events where the charges are definitely established. Six other emulsion events[2,4,5,15] may be included in the analysis if it is assumed that the parent τ meson is of positive charge. The data on these eleven events is given in Fig. 3. Three events (each observed in a single emulsion layer) for which only a π^+ meson is identified have also been included—the assumption of a τ^+ parent still allows two possible positions for the corresponding point. These have been included in order to emphasize the possibility of systematic bias in the data. For example, if we suppose the decaying τ mesons to be positive, then for an event leading to a slow π^- meson to be included in this plot, it is only necessary for the π^- meson to come to rest and be identified. But for an event giving a slow π^+ meson to be included, it is necessary that at least two π mesons come to rest in the emulsion; and since the second of these must be quite fast, the probability of this occurrence is considerably less, from geometrical considerations. It is clear that no definite conclusions[16] can be reached at the present stage owing to uncertainties of this kind and to the small number of events available. The purpose of presenting such a discussion at the present time is rather to draw attention to the necessity for assessing these uncertainties when the data are collected from block emulsions of various dimensions and examined by differing techniques. It should also be remarked that τ-meson data obtained from cloud-chamber events with a magnetic field applied are not subject to these uncertainties and it has been shown by Van Lint and Trilling[6] that these may be sufficiently accurate to allow a clear picture of the event in the τ-meson rest system to be deduced.

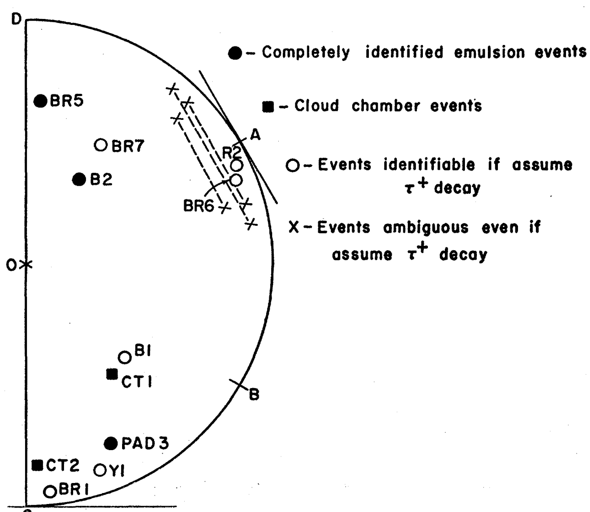

FIG. 3. The data on τ-meson decay events in which the signs of π-meson charges are established.

In Fig. 4, 29 available τ-meson events are plotted, without regard to knowledge of charges. This distribution is not yet inconsistent with a random distribution, nor does it give evidence for a tendency for the events to crowd towards the corner B, a distortion which would be characteristic of a strong meson-meson interaction.

4. CONCLUSION

The qualitative features of the statistics of τ-meson decay events, from which some indications concerning the parity and spin of the τ meson may be obtained when more data are available have been discussed. The knowledge of j and w would be of considerable interest, especially on account of the questions which have arisen concerning the possible relationships of the

[15] Brown, Camerini, Fowler, Muirhead, Powell, and Ritson, Nature **163**, 82 (1949). This event $BR1$, the first τ meson reported, was observed in an emulsion of thickness 600μ. All other emulsion events mentioned above have been observed in "stripped emulsions."

[16] However, the number of events in which the unlike π meson is much the slowest is not inconsistent with, and perhaps suggests a least L value of $L=0$. If this is still the case when the number of available events is more adequate, it would imply a negative parity and even spin for the τ meson.

τ meson with the χ meson[17] and with the θ^0 particle.[18] The angular momentum and parity selection rules governing the possibility of competition between 2π and 3π decay of a heavy meson are well known—in particular, 2π decay is forbidden unless $w=(-1)^j$. Other selection rules have also been proposed[19] which would forbid this competition and which originate from the requirements of invariance of the theory with respect to charge symmetry (relevant to the θ^0 decay) and charge conjugation (both relevant in the $\tau^{\pm}$ decay). These selection rules are however not absolute and the experimental evidence on unstable supernucleonic particles suggests that charge symmetry may not hold for these [in particular there does not appear to be a charged counterpart to the well-known $V_0{}^1(\Lambda^0)$ particle]. Such a failure would have only minor effects in situations where charge symmetry is most accurately tested. However, insofar as the τ meson may be strongly coupled with these supernucleons, it is very much a possibility that the violation of charge symmetry for the τ meson might be sufficient to permit the competition of a 2π decay with the well established 3π-decay mode.

In the present paper, it has been shown that this question of the possibility of a competitive 2π decay for the τ meson could be settled (at least in the negative) from a qualitative study of the τ-meson decay statistics. This could decide to which of four classes the τ meson belongs, the 2π decay being forbidden for two of these classes. At the present stage, the number of τ-decay events giving a slow unlike π meson rather suggests that the least L is $L=0$, which would imply that the τ meson belongs to the class of even j and odd w, a class for which the 2π decay is forbidden. This tentative conclusion is given some support by the existence of the two events $R2$ and $BR6$ since the condition $w=(-1)^j$ necessary for 2π competition to be possible, requires the τ-meson decay probability to have an over-all factor $\sin^2\theta$ and therefore to be small on the ellipses of constant θ close to the semicircular boundary $(\theta=0)$. In conclusion, it should be emphasized that any such conclusion can be only tentative at the present, in view of the small number of events available for analysis and the possibility that there may be some experimental bias favoring observation of events in which a slow π meson is emitted.

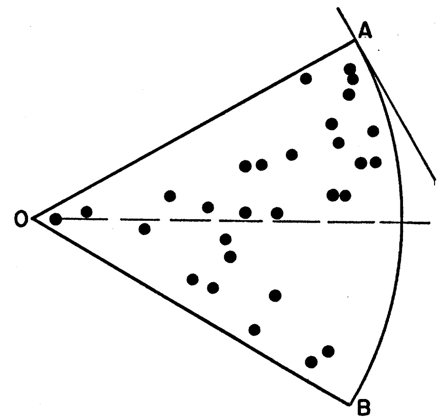

FIG. 4. The data on twenty-nine τ-meson decay events.

It is a pleasure to acknowledge here the assistance of all those groups and individuals who have contributed to this investigation by sending detailed information concerning τ-meson decay events observed by them.

[17] M. G. K. Menon and C. O'Ceallaigh, Proc. Roy. Soc. (London) **A221**, 292, 1954.

[18] Thompson, Buskirk, Etter, Karzmark, and Rediker, Phys. Rev. **90**, 329 (1953); K. H. Barker, Proc. Roy. Soc. (London) **A221**, 328, 1954.

[19] A. Pais and R. Jost, Phys. Rev. **87**, 871 (1952); L. Michel, Proceedings of the International Cosmic Ray Conference, July, 1953 (unpublished).