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WEAK INTERACTIONS OF STRANGE PARTICLES (EXPERIMENTAL)

Berkeley, California

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F. S. Crawford

July 1962

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I will not attempt to summarize all results that have appeared since the 1960 Rochester Conference. In particular I will omit some subjects which were discussed at the Aix-en-Provence International Conference on Elementary Particles, in September 1961, and for which no new material has been presented to this conference.

In several of the experiments I will discuss, one measures the decay parameters α, β and γ for a parent baryon of spin ½ decaying into a daughter baryon of spin ½ plus a pion (spin zero). The decays of interest are $\Xi^- \to \Lambda + \pi^-$ (here the Ξ^- spin is not yet proven to be ½, as we shall see), $\Lambda \to p + \pi^-$, $\Lambda \to n + \pi^0$, $\Sigma^+ \to n + \pi^+$, $\Sigma^+ \to p + \pi^0$ and $\Sigma^- \to n + \pi^-$.

Let us first review the meaning of the decay parameters, and how they are measured. By angular momentum conservation only the states $S_{1/2}$ and $P_{1/2}$ are available to the daughter baryon and pion. ("Baryon" will always mean spin ½, here.) Both states are usually present, i.e. parity is not conserved. If S and P are the complex amplitudes, four real numbers describe the decay. Four is reduced to three when we neglect an overall phase. The usual parameters are

$$\alpha = -2\mathrm{Re}\, S^*P/\,(|S|^2 + |P|^2)\,,$$

$$\beta = 2\,\mathrm{Im}\, S^*P/\,(|S|^2 + |P|^2) \quad \text{and}$$

$$\gamma = (|S|^2 - |P|^2)/(|S|^2 + |P|^2).$$

If T invariance holds, β is zero, except for final state interactions. Notice that α is invariant under the interchange of S and P, so that a measurement of α gives $|S|/|P|$ <u>or</u> $|P|/|S|$. To

resolve the ambiguity one must measure the sign of γ.

For a parent baryon with 100% polarization along the + z axis, the wave function for the daughter baryon's spin and angles ϑ(polar) and ϕ(azimuth) of emission is given by

$$\Psi = (S + P \cos \vartheta)\uparrow + (Pe^{i\phi} \sin \vartheta)\downarrow, \qquad (1)$$

so that the decay distribution is given by

$$\frac{dN}{d \cos \vartheta} \sim |\Psi|^2 = |S + P \cos \vartheta|^2 + |Pe^{i\phi} \sin \vartheta|^2 =$$

$$(|S|^2 + |P|^2)(1 - \alpha \cos \vartheta). \qquad (2)$$

If the parent is not 100% polarized but has polarization p, then in Eq. (2) α becomes αp. Therefore an "up-down" measurement of a decay asymmetry (distribution in ϑ) does not give α, but gives αp. The polarization p depends on the strong process by which the parent baryon is produced. By parity conservation (strong process) the direction of p is always perpendicular to the production plane.

In the experiments I will first describe, (Ξ^--decay, by the Brookhaven-Syracuse group[1], and by the Berkeley[2] - U.C.L.A.[3] group; and Λ-decay, by Cronin and Overseth[9] the experimenters measure α directly, using in each case a parent baryon which is guaranteed to be completely unpolarized. We will now explain how they do this.

The first question is, how do they get unpolarized parents, when we know that in general p is not zero, and in fact is often found to be nearly 1. The answer is that to get "effectively" unpolarized parents they simply throw away information as to the orientation of the production plane. The odd term, $- \alpha p \cos \vartheta$, then averages to zero. This "depolarization" trick works only for spin ½. For spin ³⁄₂, for instance, there could be terms in $\cos^2 \vartheta$ that would not average to zero.

The next observation is that with an unpolarized source of parent baryons (spin ½), the daughter baryon has a longitudinal polarization of $-\alpha$. We can see this easily from Fig. 1. We quantize along the direction of emission of the daughter baryon. The two equal populations of spin-up and spin-down parents are at the centre of the diagram. Then, since we are quantizing along the direction of the linear momentum, the daughter baryon's spin is in the same direction as that of the parent; the orbital angular momentum in the final state is perpendicular to the linear momentum and therefore cannot flip the baryon spin. For a given parent spin we see from Eq. (2) that the number of daughters emitted along the spin is proportional to $(1 - \alpha)$ = "along", and the number against the spin to $(1 + \alpha)$ = "against". From the diagram we then see that for a given direction of emission the average longitudinal polarization of the daughter is [(along) - (against)]/[(along) + (against)] = $-\alpha$.

Next one must measure the longitudinal polarization of the daughter, to measure $-\alpha$ of the parent. For instance, in the decay $\Xi^- \to \Lambda + \pi^-$, the daughter Λ will as we have just seen have the longitudinal polarization $p_\Lambda = -\alpha_{\Xi^-}$ along its direction of motion (with respect to the Ξ^- rest frame). We therefore look, with respect to this direction, at the decay asymmetry for emmission of the proton, in the cases where we observe $\Lambda \to p + \pi^-$. From Eq. (2) this determines $-\alpha_\Lambda p_\Lambda = \alpha_\Lambda \alpha_\Xi$. Notice that all Ξ^- decays are useful, and that ⅔ of the Λ decay visibly.

The experimental situation is much more difficult when one wishes to measure α_Λ, as for example in the spark chamber experiment of Cronin and Overseth. To measure the longitudinal polarization $p_{proton} = -\alpha_\Lambda$ of the proton in $\Lambda \to p + \pi^-$, one must scatter the proton, for example from carbon plates, and look for scattering asymmetry. The scattering probability is typically 1/50 compared to the ⅔ for Λ decay in the Ξ^- analysis. Furthermore for

the scattering analysis not all Λ decays are useful. One needs decay protons transversely polarized in the laboratory frame (where the carbon plates are). For an unpolarized Λ decaying at rest in the laboratory you would have no transversely polarized protons at all. But for the fast Λ's used, the velocity of the Λ with respect to the laboratory is large compared to the velocity of the decay proton with respect to the Λ rest frame, so that for four out of the "six possible directions" ($\pm x$, $\pm y$, $\pm z$) of proton emission with respect to the Λ rest frame, one has transverse polarization in the laboratory frame. This is illustrated in Fig. 2, which is a diagram in velocity space with the addition of arrows to give the spin directions. Since the Λ is unpolarized in the α determination, it has no arrow. Neither does the carbon nucleus. The two proton-emission directions in parenthesis are useless since they give no transverse polarization with respect to the carbon.

The carbon has a large analyzing power, given by the parameter $\langle S \rangle$, which has magnitude about 0.6. The experimenters determine $p_\Lambda \langle S \rangle = - \alpha_\Lambda \langle S \rangle$, from the scattering asymmetry with respect to the plane formed by the three points (in velocity space) of the carbon (lab.), Λ, and proton. The magnitude of $\langle S \rangle$ is independently determined in double-scattering experiments of protons on carbon.

Next we consider how the experimenters measure β. Since β vanishes if T (time reversal) invariance holds (and if final state interactions are negligible), we look for a suitable polarization which should vanish under T. To do this we will see that we need a polarized parent, and must measure the daughter polarization. The suitable polarization is shown in Fig. 3, which is again a velocity and spin diagram.

If T-invariance holds then the decay in Fig. 3c occurs as frequently as that in Fig. 3a, so that there can be no net polarization of the type of Fig. 3a. Thus the experimenter

looks at decays where the daughter is emitted in the production plane of the parent, and looks for a daughter polarization perpendicular to the velocity of the daughter with respect to the parent, and lying in the production plane. In the Ξ^- decay analysis, by means of subsequent Λ decays, four of the "six possible" decay directions are useful. In the Λ decay analysis by subsequent proton-carbon scatters, only two of the six directions are useful. This is illustrated in Fig. 4, where the useless directions are in parenthesis.

(In this discussion our language is of course over simplified. The various polarizations always vary linearly with the cosine of some appropriate polar angle; our "useless" directions are those where the effect is zero, "useful" where it is maximum. In practice it is important for the experimenter to verify the angular dependences, to check for biases and to use all of the data.)

Next we consider how the experimenters measure γ, to tell whether S or P predominates. Again we need polarized parents. Consider first pure S-wave in the decay. Then for all directions of emission, the daughter has the same spin direction as the parent, since no orbital angular momentum is available to flip the spin. This is also evident from Eq. (1) if we let $P = 0$. Next consider pure P-wave decay. For decays along the direction of parent polarization, i.e. perpendicular to the production plane, the orbital angular momentum (a.m.) cannot flip the spin, since the orbital a.m. is perpendicular to the linear momentum. For decays in the production plane the spin of the daughter is opposite that of the parent. This is evident from Eq. (1), with $S = 0$, and with $\cos\vartheta = 1$ or 0, respectively. In both the Ξ^--decay and the Λ-decay experiments, "all six directions" are useable. This is illustrated for the Λ analyis in Fig. 5a, b. We see that the two extremes of predominantly S and predominantly P are easily distinguishable. Equation (1) shows how the polarization varies for intermediate cases. We turn now to the experiments.

1. $\Xi^- \to \Lambda + \pi^-$

This decay has been studied by a Brookhaven-Syracuse group[1] ("East") and by a U.C. Berkeley[2], U.C.L.A.[3] group ("California"). The California Ξ^- are produced in the 72-inch chamber through the reaction $K^- + p \to \Xi^- + K^+$, with K^- of 1.2 to 1.6 GeV/c (Berkeley) or 1.8 GeV/c (U.C.L.A.). The Eastern Ξ^- are produced in the same reaction, and also in reactions where K^+ is replaced by $K^+ + \pi^\circ$, or $K^\circ + \pi^+$. They use K^- of 2.3 and 2.5 GeV/c. Where possible we will include a comparison with early results of Fowler et. al[4].

A. Decay parameters (assuming the Ξ^- spin is ½)

Experimenters	No. events	$\alpha_{\Xi^-} \alpha_\Lambda$	α_{Ξ^-}	β_{Ξ^-}	γ_{Ξ^-}
Eastern[1]	75	-0.63±0.20	$+1^{+0}_{-0.35}$		
Berkeley[2]	450	-0.30±0.08	+0.49±0.14	-0.63±0.31	+0.63±0.31
U.C.L.A.[3]	100	-0.52±0.13	+0.85±0.23	-0.85±0.53	-
Calif. avg.	550	-0.38±0.06	+0.62±0.11	-0.68±0.27	-
Fowler et.al[4]	18	-0.65±0.35	$+1^{+0}_{-0.55}$	-	-

There now seems to be absolutely no doubt that α_Ξ and α_Λ have opposite signs. This fact rules out some theories which predict $\alpha_\Xi = \alpha_\Lambda$, the Weak Global Symmetry models of, for instance, d'Espagnat and Prentki[5], and of Treiman[6].

The value of α_Ξ (fourth column of table) is obtained by dividing $\alpha_\Lambda \alpha_\Xi$ by $\alpha_\Lambda = -0.61 \pm 0.05$, which is the recent value of Cronin and Overseth[9]. We notice that the Calif. avg. value, $\alpha_{\Xi^-} = +0.62 \pm 0.11$, satisfies within the errors the relation $|\alpha_\Xi| = |\alpha_\Lambda|$. Thislast relation is predicted, for instance, by the Doublet Approximation[7].

The sign convention for α can be remembered as follows. The fact that α_Λ is negative means that the decay proton likes to be emitted in the direction of the Λ spin. Therefore it likes to be right-handed (positive helicity).

The Calif. avg. value for β_{Ξ^-} (fifth column) differs from zero by 2.5 standard deviations, and is furthermore large in magnitude, if we neglect the large error. If Berkeley's large and positive value for γ_Ξ (last column) is substantiated then it will imply mostly S-state for the final $\pi - \Lambda$ system. The Ξ^- mass is only about 60 MeV below the Y_1^* resonance (which has a half width of about 25 MeV). If the Y_1^* spin is ½ (not known), and if the Ξ^- spin is really ½ (not proven), then a large value of β is presumably easily explained in terms of $\pi - \Lambda$ interaction in a fianl S-state. There are too many "ifs" here, and too little data. We leave this question to the discussion.

B. Lifetime and mass of Ξ^-

Experimenters	Mass	Mean life
Brookhaven-Syracuse[1]	1321.0 ± 0.5 MeV	$1.16 \begin{smallmatrix}+0.26\\-0.17\end{smallmatrix} \times 10^{-10}$ sec
Fowler et. al[4]	1317.9 ± 1.9 MeV	$1.28 \begin{smallmatrix}+0.41\\-0.25\end{smallmatrix} \times 10^{-10}$ sec

"Weak Global Symmetry"[6] predicts (weakly?), $\tau_{\Xi^-} = (3/2)\,\tau_\Lambda$, which becomes $\tau_{\Xi^-} \approx \tau_\Lambda$ after a phase space correction. Since τ_Λ is known to be either 2.8 ("Western value", see para. 10 E) or 2.4 ("Eastern value", ditto remark) $\times 10^{-10}$ sec, the prediction fails.

C. Spin of the Ξ^-

Suppose the Ξ^- is strongly polarized (relative to the production plane) in the production process $K^- + p \rightarrow \Xi^- + K^+$. Also suppose that the admixture of opposite parities in the decay is large; i.e. comparable amounts of $S_{1/2}$ and $P_{1/2}$ if the spin is ½,

$P_{3/2}$ and $D_{3/2}$ if the spin is $3/2$, etc. Then in the decay $\Xi^- \to \Lambda + \pi^-$ one can obtain a large "up-down" asymmetry in the number of π^- emitted above and below the production plane. (We consider the π^- rather than the Λ, to emphasize that we make no use of the Λ decay.) The large possible up-down ratio is $3/1$, and this can be achieved only for a Ξ^- spin of $1/2$, and with maximum parity non-conservation and maximum polarization, namely with, $|\alpha_\Xi| = 1$ and $|p_\Xi| = 1$. The higher the spin, the smaller is the maximum up-down asymmetry. (This is perhaps easily believed from the classical limit of large spin, i.e. a decaying flywheel. Polar fragments carry no "useful" angular momentum. Therefore most of the decay fragments are "required" to go off in the equatorial plane in order to conserve angular momentum. At least this is so if the decay is not very exothermic!)

The experimenters find the following values for $3\,\xi$(avg.), where ξ is the cosine of the decay π^- with respect to the normal to the production plane, and the average is taken over all of the decays.

Experimenters	$3\,\xi$(avg.)
Brookhaven-Syracuse[1]	$+ 0.52 \pm 0.26$
U.C.L.A.[3]	$+ 0.51 \pm 0.17$

If the spin of the Ξ^- is J, then the magnitude of $3\,\xi$(avg.) must be less than $1/2 J$, provided that the distribution in ξ is linear[8]. For spin $1/2$ this sum is $\alpha_\Xi\, p_\Xi$. For spin $3/2$ the upper limit is $1/3$. This is exceeded by 1 std deviation for the U.C.L.A. data, and by 0.7 std. dev. for the Eastern data. For spin $5/2$ the limit is $1/5$, exceeded by 1.8 std. dev. by U.C.L.A. and by 1.23 std. dev. by the East.

Of course if the spin is J, the distribution in ξ can go up to ξ^{2J}, so that it is not fair to assume that the distribution is linear. The above test is therefore not strictly valid. A valid test is provided by the Lee-Yang test functions[8]. For spin

$3/2$ they define $T_{3/2,3/2} = 9P_1(\text{avg.}) + 5P_2(\text{avg.}) - (7/3)P_3(\text{avg.})$, which must be less than 1 if the spin is $3/2$. If $P_2(\text{avg.}) = P_3(\text{avg.}) = 0$ we get the simpler but invalid (to an experimentalist) test "assuming a linear distribution". Similar test functions are constructed for higher spins. The Eastern experimenters[1] find

$$T_{3/2,\,3/2} = 1.6 \pm 0.9 > 1?$$

$$T_{5/2,\,5/2} = 3.7 \pm 1.7 > 1?.$$

They thus find the spin $3/2$ condition violated by $(0.6/0.9) = 0.7$ std. dev., and the spin $5/2$ condition violated by $2.7/1.7 = 1.6$ std. dev. Clearly more dataare needed, even to rule out spin $5/2$.

2. Decay parameters for $\Lambda \to p + \pi^-$

The experiments are listed in inverse chronological order.

Experimenters	Λ-Source	Detector	α	β	γ
Cronin and Overseth[9]	$\pi^- + p$	Spark C	-0.62 ± 0.05	$+0.19 \pm 0.19$	$+0.78 \pm 0.04$
Gray et. al[10]	$K^- + He$	He B.C.	-0.66 ± 0.25	-	-
Beall et. al[11]	$\pi^- + p$	Spark C.	$-0.67^{+0.13}_{-0.17}$	assume = 0	$+0.74^{+0.09}_{-0.23}$
Birge and Fowler[12]	$\pi^- +$ propane	Propane B.C.	-0.45 ± 0.4	-	-
Bolt et. al[13]	$\pi^- +$ iron	Cloud C.	$+0.85^{+0.15}_{-0.21}$	-	-

In listing the first three experiments in the table, I have converted the experimenters' published errors, obtained by going down by a factor e^{-1} on a likelihood function, to the more customary values obtained by going down by $e^{-1/2}$; this usually means I divided their errors by $\sqrt{2}$.

We see that α is now fairly well known. The early sign discrepancy is resolved. The sign of α is opposite to that predicted by application of UFI to Λ decay, by Okubo et al.[14]. As to the magnitude, an additional recent result is relevant. This is obtained by measurement of the decay asymmetry as a function of production angle in the reaction $\pi^- + p \to \Lambda + K^0$.

My collaborators and I find that $\alpha p(\vartheta)$ is 0.68 ± 0.07 at its maximum[15]. This is consistent with the value of Cronin and Overseth, if our Λ's are 100% polarized.

The value of β found by Cronin and Overseth is consistent with CP-invariance, taking into account the final state interactions from the known π-p phase shifts[9]. Experimenters with unpolarized sources of Λ's cannot measure β or γ. This explains the vacancies in the table. Beall et al. assume $\beta = 0$, but this affects hardly at all their results for α and γ

The above results for γ show that the S-wave dominates in $\Lambda \rightarrow p + \pi^-$. This result has been used to show that the spin of ${}_{\Lambda}H^4$ is 0, and that therefore the K Λ and πN parities are probably the same[16].

3. The decay $\Lambda \to n + \pi^\circ$

If the $\Delta I = \frac{1}{2}$ rule holds for $\Lambda \to$ (nucleon + pion), then for the decay amplitudes A we have $A(n\,\pi^\circ) = -2^{-1/2}\,A(p\,\pi^-)$, so that the decay parameters α, β and γ should be the same for the two decay modes, and the decay rates should give $B_\Lambda \equiv (\Lambda \to p\,\pi^-)/(\Lambda \to p\,\pi^-) + (\Lambda \to n\pi^\circ) = 0.660$. (This is $\frac{2}{3}$, with a small phase space correction.)

One should remember that these same predictions follow if $\Delta I = \frac{3}{2}$ is also present, provided that $\Delta I = \frac{3}{2}$ and $\frac{1}{2}$ amplitudes are in the ratio $A_{3/2} = -2\sqrt{2}A_{1/2}$[14].

A. Decay parameter α

Using counters, Cork et al.[17] have measured up-down decay asymmetries for $\Lambda \to p + \pi^-$, and for $\Lambda \to n + \pi^\circ$. The Λ were produced via $\pi^+ + d \to K^+ + \Lambda + p$. The geometry was the same in the two determinations, so that the polarization of the Λ was the same. Thus they can cancel the factor p_Λ. They find $\alpha_\Lambda(n\pi^\circ)/\alpha_\Lambda(p\pi^-) = p_\Lambda\,\alpha_\Lambda(n\pi^\circ)/p_\Lambda\,\alpha_\Lambda\,(p\pi^-) = +\,1.10 \pm 0.27$. This is in agreement with the prediction 1.00 of the $\Delta I = \frac{1}{2}$ rule.

B. Decay parameter γ_0

Determination of α gives S/P or P/S but does not tell whether S or P predominates. No direct measurements of α, β or γ have yet been made, for $\Lambda \to n + \pi^\circ$ because of the difficulty of measuring the scattering asymmetry of the neutrons. By an indirect method, Block et al.[18] have determined γ, as follows. They measure R, the decay rate for ${}_\Lambda He^4 \to$ (all π° modes) divided by the decay rate for ${}_\Lambda He^4 \to$ (all π^- modes), and find $R = 2.28 \pm 0.43$. The spin of ${}_\Lambda He^4$ is believed to be zero[18]. The decays ${}_\Lambda He^4 \to$ (all π° modes) are calculated by Dalitz and Liu[19] to be mostly via the mode ${}_\Lambda He^4 \to \pi^\circ + He^4$. This mode goes only through S-wave (for spin zero ${}_\Lambda He^4$). Thus the numerator of R is very sensitive to the ratio S_0/P_0 for $\Lambda \to n + \pi^\circ$.

Using the known branching ratio $\Gamma(n\pi^\circ)/\Gamma(p\pi^-)$ for free Λ decay, and the known[11] S/P ratio for $\Lambda \to p + \pi^-$, they obtain the formula[19] $R = 2.51 - 2.06\ P_0^2/(S_0^2 + P_0^2) \equiv 1.48 + 1.03\ \gamma_0$. Their result for R gives $P_0^2/(S_0^2 + P_0^2) = 0.11\ ^{+0.21}_{-0.11}$, which is equivalent to $\gamma_0 = +\ 0.78\ ^{+0.22}_{-0.42}$. They thus favour predominance of S-wave in $\Lambda \to n + \pi^\circ$.

C. Branching ratio B_Λ

Our result is the only new value reported[15]. We find $B_\Lambda = 0.685 \pm 0.017$, by counting the charged decays.

For comparison we list values from the 1960 Rochester Conference[20]

$B_\Lambda = 0.72 \pm 0.08$ Baglin et al. (counts neutrals).

$B_\Lambda = 0.65 \pm 0.05$ Columbia group (counts charged).

$B_\Lambda = 0.63 \pm 0.03$ Crawford et al.[21] (counts charged).

$B_\Lambda = 0.65 \pm 0.05$ Brown et al. (counts neutrals).

There is no serious disagreement among experimenters, nor with the value 0.660 predicted by the $\Delta I = \frac{1}{2}$ rule.

4. $\Sigma \to n + \pi$ Decays and the $\Delta I = \frac{1}{2}$ rule

A. $\Sigma^+ \to p + \pi^\circ$ decay parameter α_0

This has been measured by observing the scattering asymmetry of the decay proton in a spark chamber, by Beall et al.[11] They obtain $\alpha_0 = + 0.78 \begin{smallmatrix} + 0.08 \\ - 0.09 \end{smallmatrix}$. (This agrees with theories involving Global Symmetry, or Doublet Approximation, which predict $\alpha_0 = - \alpha_\Lambda$. See, for instance, Refs. 5, 6, 7.) The Σ^+ were produced by 1.23 GeV/c π^+ in the reaction $\pi^+ + p \to \Sigma^+ + K^+$. The Σ^+ polarization was small, so that β_0 and γ_0 were not measureable.

B. $\Sigma^+ \to n + \pi^+$, decay parameter α_+

Cork et al.[17] have measured both Σ^+ decay asymmetries in the same geometry, in a counter experiment, and obtained $\alpha_+ \bar{p}_{\Sigma^+} = 0.03 \pm 0.08$, $\alpha_0 \bar{p}_{\Sigma^+} = + 0.75 \pm 0.17$. Since the Σ^+ polarization is the same in each case, they can take the ratio, cancelling $\bar{p}_{\Sigma^+}$, to obtain α_+/α_0. Multiplying by the measured value[11] of α_0 they get $\alpha_+ = + 0.03 \pm 0.08$. The reaction was $\pi^+ + p \to \Sigma^+ + K^+$, as in case A, but at a lower momentum, 1.13 GeV/c. The polarization was large.

C. $\Sigma^- \to n + \pi^-$, decay parameter α_-

This quantity has resisted measurement via up-down asymmetry because of uncertainty as to the polarization of the Σ^-. Franzini et al.[22] found $\alpha_- \bar{p}_{\Sigma^-} = 0.01 \pm 0.17$, from Σ^- produced by π^- of 1.23 GeV/c, in the reaction $\pi^- + d \to \Sigma^- + K^\circ + p$. The idea is to hope the impulse approximation works, so that this reaction is essentially $\pi^- + n \to \Sigma^- + K^\circ$, and then to use charge symmetry to say that the Σ^- polarization is the same as in $\pi^+ + p \to \Sigma^+ + K^+$ at the same momentum. The trouble is that Beall et al.[11] and also Baltay et al.[23] find samll Σ^+ polarization if any, at 1.23 GeV/c, for $\pi^+ + p \to \Sigma^+ + K^+$.

Recently Tripp, Watson and Ferro-Luzzi[24] have discovered a K^-p resonance with mass 1520 MeV, in the state $D_{3/2}$, I = 0. The outgoing channels are about 60% $\Sigma\pi$. Thus the Σ^- and Σ^+ have the same polarization. They find a large Σ^+ decay asymmetry and thus a large $\Sigma^\pm$ polarization. They then find $\alpha_- = +0.16 \pm 0.21$[25].

Another determination of α_- has been recently obtained by Nussbaum et al.[26] using film from the 72-inch deuterium chamber associated-production run. They studied the reactions

$$\pi^+ + d \rightarrow a(+) = \Sigma^+ + K^+ + n, \text{ and}$$

$$b(+) = \Sigma^+ + K^\circ + p,$$

and the corresponding charge-symmetric (CS) reactions

$$\pi^- + d \rightarrow a(-) = \Sigma^- + K^\circ + p, \text{ and}$$

$$b(-) = \Sigma^- + K^+ + n,$$

using pions of 1.19 GeV/c.

There preliminary results are

$\alpha_0 \bar{p}_{\Sigma^+} = +0.61 \pm 0.29$ for a(+); -0.52 ± 0.41 for b(+), and

$\alpha_- \bar{p}_{\Sigma^-} = +0.27 \pm 0.22$ for a(-); $+0.17 \pm 0.16$ for b(-).

Since CS guarantees $\bar{p}_{\Sigma^+} = \bar{p}_{\Sigma^-}$ for a, and also for b, we can divide and obtain

$\alpha_-/\alpha_0 = +0.44 \pm 0.40$ for a(±); -0.33 ± 0.43 for b(±),

which average to

$\alpha_-/\alpha_0 = +0.05 \pm 0.30$; or, using the known value[11] of α_0, we get

$\alpha_- = +0.04 \pm 0.23$.

D. Consequences for the $\Delta I = \frac{1}{2}$ rule

The triangle relationship[27] that follows from the $\Delta I = \frac{1}{2}$ rule is, in the notation of Gell-Mann and Rosenfeld[27], $\sqrt{2}\vec{N}_0 + \vec{N}_+ = \vec{N}_-$, with $\vec{N} = \vec{S} + \vec{P}$. The vectors $\vec{N}$ are real, by T-invariance, and since the final state phase shifts are small[27]. Therefore they can be represented as vectors in the S-P plane. The magnitudes of the vectors are determined from the three decay rates, which are almost exactly equal[27,28], within the errors. Using α_0, α_+ and α_- from Refs. 11), 17) and 25), Tripp et al. construct Fig. 6. The triangle relationship is not well satisfied, for either choice for the S-P ambiguity. The inconsistency with the $\Delta I = \frac{1}{2}$ rule is between two and three standard deviations, for the "closest" choice.

If we average the value for α_- of Nussbaum et al.[26] with that of Tripp et al.[25] we find $\alpha_- = + 0.10 \pm 0.16$. This will slightly increase the discrepancy with $\Delta I = \frac{1}{2}$, by reducing the "5 deg" of N_- in Fig. 6, to 3 deg.

It is clearly extremely important to determine the decay parameters α_+, α_- and especially α_0 with greater accuracy. Even more informative would be the determination of γ_+, γ_- and γ_0, to give the S/P ratios. From Fig. 6, the "worst" possibility would correspond to more than 3 std deviations against $\Delta I = \frac{1}{2}$. Of course if the $\Delta I = \frac{1}{2}$ rule does not hold it is even possible for $\Sigma^+ \to n + \pi^+$ and $\Sigma^- \to n + \pi^-$ to both be pure S-wave, or both pure P-wave.

5. Leptonic (L) decays of Strange Particles and the rules $\Delta I = \frac{1}{2}$ (L-decays), and $\Delta S = \Delta Q$

The following table lists ΔS, ΔQ, $|\Delta I|$, and $|\Delta I_z|$ for the strongly interacting particles, in the decays to be discussed. L will stand for either a muon or an electron. The notation will not distinguish between various kinds of neutrinos.

Decay	ΔS	ΔQ	$\Delta S/\Delta Q$	$(\lvert\Delta I\rvert, \lvert\Delta I_z\rvert)$
$\Sigma^- \to n + L^- + \nu$	+1	+1	+1	$(\frac{1}{2}, \frac{1}{2})$ or $(\frac{3}{2}, \frac{3}{2})$
$\Sigma^+ \to n + L^+ + \nu$	+1	-1	-1	$(\frac{3}{2}, \frac{3}{2})$ only
$K^+ \to \pi^\circ + L^+ + \nu$	-1	-1	+1	$(\frac{1}{2}, \frac{1}{2})$ or $(\frac{3}{2}, \frac{1}{2})$
$K^\circ \to \pi^- + L^+ + \nu$	-1	-1	+1	$(\frac{1}{2}, \frac{1}{2})$ or $(\frac{3}{2}\ \frac{1}{2})$
$K^\circ \to \pi^+ + L^- + \nu$	-1	+1	-1	$(\frac{3}{2}, \frac{3}{2})$ only
$\bar{K}^\circ \to \pi^+ + L^- + \nu$	+1	+1	+1	$(\frac{1}{2}, \frac{1}{2})$ or $(\frac{3}{2}, \frac{3}{2})$
$\bar{K}^\circ \to \pi^- + L^+ + \nu$	+1	-1	-1	$(\frac{3}{2}, \frac{3}{2})$ only

A. The decay $\Sigma^+ \to n + \mu^+ + \nu$

A clear-cut example of this decay has very recently been found by Galtieri et al.[29]. It satisfies $\Delta S/\Delta Q = -1$. All of the suggested interpretations alternative to the muonic decay have been shown to be exceedingly unlikely. Only the "philosophical" arguement "There is only one event" remains.

B. Three Body Leptonic Decays of K_1° and K_2°

(a) $\Delta I = \frac{1}{2}$ Rule and $K_2^\circ \to \pi^\pm + L^\mp + \nu$

The absolute rate for K_2° decaying into e^+, e^-, μ^+ and μ^- has been measured by Alexander, Almeida, and Crawford[30,31]. They sum over all four decay modes, and obtain the total L decay rate $\Gamma_2(L^\pm) = 9.31 \pm 2.49 \times 10^6\ \text{sec}^{-1}$.

According to the $\Delta I = \frac{1}{2}$ rule, $\Gamma_2(L^{\pm}) = 2\Gamma_{K^+}(\pi^0 L^+ \nu) = 16.5 \pm 1.18 \times 10^6\ \mathrm{sec}^{-1}$. The discrepancy between the measurement and the prediction gives $^{50}/_1$ odds agains $\Delta I = \frac{1}{2}$. It implies that one or both of $(\frac{3}{2}, \frac{1}{2})$ and $(\frac{3}{2}, \frac{3}{2})$ are present.

(b) <u>$\Delta S = \Delta Q$ rule and $\Gamma_1/\Gamma_2 = \Gamma(K_1^0 \to \pi^{\pm} L^{\mp} \nu)/\Gamma(K_2^0 \to \pi^{\pm} L^{\mp} \nu)$</u>

If $(\frac{3}{2}, \frac{3}{2})$ is absent, i.e. if $\Delta S = -\Delta Q$ is absent, one has the prediction $\Gamma_1(L^{\pm}) = \Gamma_2(L^{\pm})$ for $L = \mu$ or e.
Ely, et al.[32] have been the first to suggest that the $\Delta S = \Delta Q$ rule fails. They find $\Gamma_1(e^{\pm})/\Gamma_2(e^{\pm}) = 11.9 \begin{smallmatrix}+7.5\\-5.6\end{smallmatrix}$.
Alexander, Almeida and Crawford[30,31] find $\Gamma_1(L^{\pm})/\Gamma_2(L^{\pm}) = 6.6 \begin{smallmatrix}+6.0\\-4.0\end{smallmatrix}$. In an earlier experiment, Crawford et al.[33] found $\Gamma_1(L^{\pm})/\Gamma_2(L^{\pm}) = 3.5 \begin{smallmatrix}+3.9\\-2.7\end{smallmatrix}$. (No priority claim!! This result was, and is, consistent with unity, and was so taken.) This same experiment[33] gives $\Gamma_2(L^{\pm}) = 8.5 \pm 2.8 \times 10^6\ \mathrm{sec}^{-1}$ if one assumes $\Gamma_1 = 9\Gamma_2$. It gives instead $\Gamma_2(L^{\pm}) = 20.4 \begin{smallmatrix}+7.2\\-5.6\end{smallmatrix} \times 10^6\ \mathrm{sec}^{-1}$ if one assumes $\Gamma_1 = \Gamma_2$. [The absolute value $\Gamma_2(L^{\pm})$ obtained by Alexander et al.[30,31] does not depend on Γ_1/Γ_2.]

The conclusion is that the $\Delta S = \Delta Q$ rule is probably wrong.

6. The $\Delta I = \frac{1}{2}$ rule and non-leptonic K decays

A. $K_2^0 \to \pi^+ + \pi^- + \pi^0 \equiv (+-0)$

From the $\Delta I = \frac{1}{2}$ rule one predicts[34] $\Gamma_2(+-0) = 1.032 \times 2\Gamma_+(+00) = 2.87 \pm 0.23 \times 10^6\ \mathrm{sec}^{-1}$. (See Ref. 30) for numbers.) Alexander, Almeida, and Crawford[30,31] find $\Gamma_2\ (+-0) = 2.66 \pm 1.34 \times 10^6\ \mathrm{sec}^{-1}$, in good agreement, but based on only 4 events. If instead we use the branching ratio $\Gamma_2(+-0)/\Gamma_2(\text{all charged})$ of Luers et al.[35] [which is based on 55 decays into (+-0)], together with our absolute rate for $\Gamma_2(L^{\pm})$ we find[30,31] $\Gamma_2(+-0) = 1.44 \pm 0.43 \times 10^6\ \mathrm{sec}^{-1}$, which is smaller than the prediction by a factor of 2; it is 2.95 std deviations down from the prediction of the $\Delta I = \frac{1}{2}$ rule, and corresponds to about 100/1 odds.

B. $K_2^0 \to \pi^0 + \pi^0 + \pi^0 \equiv (000)$

From the $\Delta I = \frac{1}{2}$ rule one predicts[34] $\Gamma_2(000) = \Gamma_+(++-) - \Gamma_+(+00)$ With phase space corrections and known K^+ rates this prediction becomes $\Gamma_2(000) = 1.565\ \Gamma_+\ (++-) - 1.255\ \Gamma_+(+00) = 5.55 \pm 0.27 \times 10^6\ \mathrm{sec}^{-1}$. Anikina et al.[36] have reported at this conference the branching ratio $\Gamma_2(000)/\Gamma_2(\text{all charged}) = 0.38 \pm 0.07$. If we combine their result with the absolute rate $\Gamma_2(L^{\pm})$ of Alexander et al.[30] we find[31] $\Gamma_2(000) = 4.09 \pm 1.38 \times 10^6\ \mathrm{sec}^{-1}$.

This result is just 1 std deviation below the prediction, $5.55 \times 10^6\ \mathrm{sec}^{-1}$, of the $\Delta I = \frac{1}{2}$ rule. To compare Anikina et al.[36] and Luers et al.[35] directly, we combine the two formulas of Sawyer and Wali[34], phase space and the measured K^+ branching ratios to obtain the prediction of the $\Delta I = \frac{1}{2}$ rule (independent of the admixture of the three possible I = 1 states), $\Gamma_2(000)/\Gamma_2(+-0) = (\frac{1}{2})(++-)/(+00) - \frac{1}{2} \to 0.76\ (++-)/(+00) - 0.61 = 1.94 \pm 0.21$. The combined experiments give for this ratio the value $0.38/0.134 = 2.83 \pm 0.64$, which is 1.3 standard deviations above the prediction.

In summary, from Luers et al. and Anikina et al. there is a 1.3 std dev. discrepancy with $\Delta I = \frac{1}{2}$; from Anikina et al.

and Alexander et al. there is 1 std dev: these "add", so that with Luers et al. and Alexander et al. there is a 2.95 std dev. disagreement with the $\Delta I = \frac{1}{2}$ rule.

C. K_1^0 branching ratio B(K)

The $\Delta I = \frac{1}{2}$ rule predicts $B(K_1^0) = \Gamma(K_1^0 \to 2\pi^0)/\Gamma(K_1^0) = \frac{1}{3}$. If one allows enough $\Delta I = \frac{3}{2}$ to account for the existence of $K^+ \to \pi^+ + \pi^0$ then $B(K_1^0)$ should lie between 0.29 and 0.38[27]. Three new determinations have been reported at the conference; that of Chretien et al.[37], using a heavy-liquid bubble chamber; that of Brown et al.[38] using a xenon bubble chamber; and our value from the associated production experiment in the 72-inch hydrogen chamber[15]. For comparison we then list the values reported at the 1960 Rochester Conference[20].

$B(K_1^0)$	Experimenters and method	
0.294 ± 0.021	Cretien et al.[37].	Count neutrals.
0.329 ± 0.013	Brown et al.[38]	Count neutrals.
0.260 ± 0.024	Anderson et al.[15].	Count charged.
0.32 ± 0.04	Crawford et al.[21].	10-inch H.B.C. Count charged
0.30 ± 0.04	Brown et al.	Xenon. Count neutral.
0.30 ± 0.08	Columbia.	H.B.C. Count charged
0.26 ± 0.06	Baglin et al.	Count neutrals.

No experiment disagrees with the prediction of $\Delta I = \frac{1}{2}$, except possibly that of Anderson et al.[15], whose value lies 1.2 std dev. below the supposed lower limit for the prediction. The disagreement between Anderson et al. and the (present) value of Brown et al. amounts to 2.5 std. dev.

7. Three-Body Leptonic K-Decay Spectra and V-A Theory

The decays are $K \to \pi + L + \nu$. $K = K_2^\circ$ or K^+, and $L = e$ or μ.

Only one of V and A (or S and P) can be present, so the spectra have only the (pure) possibilities S, V and T.

From the two four vectors of the K and π one can form one scalar, two vectors (themselves, or linear combinations), and one tensor. Correspondingly there is one scalar form factor f_S, two vector form factors f_V and g_V, and one tensor form factor f_T. When L is an electron the part of the spectrum containing g_V becomes unmeasureably small for kinematic reasons. When L is a muon f_V and g_V are both important.

A. $K_2^\circ \to \pi^\pm + e^\mp + \nu$ spectrum

Luers et al.[35] find from their Dalitz plot of K_2° decays in the Brookhaven 20-inch H.B.C. that (a) T does not fit; (b) either S or V fits if the form factors are allowed to be strongly energy dependent; (c) only V fits if the form factors are taken to be constant. V fits well.

B. $K^+ \to \pi^\circ + e^+ + \nu$ spectrum

Brown et al.[39], using a xenon B.C. find (a) T does not fit; (b) either S or V fits if the form factors can be strongly energy dependent; (c) only V fits for constant form factors, and it fits well.

C. Branching ratio $\Gamma_+(\pi^\circ \mu^+ \nu)/\Gamma_+(\pi^\circ e^+ \nu)$

Roe et al.[40] find 0.96 ± 0.16 for this ratio. (Xenon B.C.). Suppose now that the theory is really V. (Test later.) The e^+ spectrum depends only on $f_V(e^+)$, since the term in $g_V(e^+)$ is negligible. Assume universality. This means $f_V(e^+) = f_V(\mu^+)$. Then the branching ratio depends only on $g_V(\mu^+)/f_V(\mu^+)$. There are two solutions, $g_V(\mu)/f_V(\mu) = +0.5 \pm 0.4$ and -4.8 ± 0.4, that will give the observed branching ratio. These two solutions predict different spectra for $K^+ \to \pi^\circ + \mu^+ + \nu$. Theorists much prefer the solution 0.5 (see L. B. Okun's Rapporteur discussion).

D. $K^+ \to \pi^0 + \mu^+ + \nu$ spectrum

Dobbs et al.[41], have looked at the muon energy spectrum above 50 MeV, using a filamentary chamber plus image intensifier. They use emulsion data to normalize the counting rate below 50 MeV. They find that the spectrum corresponds to $g_V(\mu)/f_V(\mu) = -4.8$, and not at all to $+0.5$.

Brown et al. (xenon) have now looked at their spectrum[42]. They find, under the assumption of constant form factors (which is compatible with their data) (a) S does not fit; (b) T is poor but can fit (10% χ^2 probability); (c) V fits well with $g_V(\mu)/f_V(\mu) = +0.5$, and poorly with -4.8. They therefore disagree completely with Dobbs et al.[41]. The theorists are on their side. Brown et al. also analize their data so as to simultaneously determine $f_V(e)$, $f_V(\mu)$ and $g_V(\mu)$ from the e^+ rate, the μ^+ rate, and the μ^+ spectrum, without making any a priori assumption of universality. They find $f_V(\mu)/f_V(e) = 1.09 \pm 0.15$, in excellent agreement with universality. The spectrum can be seen in their paper[42].

The conclusion is that the V-A theory works here.

8. Leptonic Decays of Hyperons

A. Humphrey, et al.[43] have searched hard for muonic hyperon decays, and summarize the world's denominators, to construct a table which we repeat here. The numerators are easy to summarize - one decay $\Lambda \to p + \mu^- + \nu$ of Eisler et al.[44], and one decay $\Sigma^+ \to n + \mu^+ + \nu$ of Galtieri et al.[29], in violation of the $\Delta S = + \Delta Q$ rule. The same authors have previously[45] summarized electronic hyperonic decay rates, and these are included in their table, with one exception. That is the branching ratio $R = \Gamma(\Lambda \to p + e^- + \bar{\nu})/\Gamma(\Lambda) = 0.85 \pm 0.3 \times 10^{-3}$ reported to this conference by Ely et al.[46]. Their value of R is based on 120 events. The error represents uncertainties in detection efficiency (heavy liquid B.C.). All rates are down by roughly a factor of 10 from the predictions of Feynman and Gell-Mann.

B. Decay $\Sigma^- \to \Lambda + e^- + \nu$

Grimellini et al.[47] report the first unambiguous case, in the Helium B.C. The "denominator" is not yet known.

9. K^- and K^+ Branching Ratios

A. Becker et al[48] have measured K^- branching ratios, using K^- decaying in flight in the Helium B.C. Their results agree with emulsion experiments, but when they average their results with emulsion results and compare the grand average with the xenon results of Roe et al.[40] they find several std dev. discrepancy in the subdivision between $K_{\mu 2}$ and $K_{\pi 2}$. We reproduce the table of Becker et al. The column "present exp." is the Helium B.C. result[48]. All of the other experiments summarized in this table are also summarized in Ref. 40).

B. It is very important, in trying to understand the reported violation[30] of the $\Delta I = \frac{1}{2}$ rule for $K \to \pi + L + \nu$, and for $K \to 3\pi$, (discussed in the para. 5 and 6) to notice that as far as the 3-body K-decay modes are concerned, all of the experiments are in good agreement, with the exception of Birge et al. In calculating[30] the predictions of the $\Delta I = \frac{1}{2}$ rule, we arbitrarily omitted the results of Birge et al.

Table - K^- and K^+ Decay Branching Ratios

Decay Mode	Branching Ratios (%)					
	Present Experiment	Emulsion Experiments			Average Emulsions + This Exp.	Xenon Chamber Roe et al.
		Birge et al.	Alexander et al.	Taylor et al.		
$K_{\mu 2}$	56.8 ± 3.5	58.5 ± 3.0	56.9 ± 2.6	-	57.4 ± 2.0	64.2 ± 1.3
$K_{\pi 2}$	25.8 ± 3.0	27.7 ± 2.7	23.2 ± 2.2	-	25.6 ± 1.5	18.6 ± 0.9
$K_{\mu 3} + Ke_3 + \tau$	11.8 ± 2.0	8.1 ± 2.0	13.2 ± 2.0	-	11.0 ± 1.0	11.5 ± 0.3
τ	5.7 ± 0.9	5.6 ± 0.4	6.8 ± 0.4	5.2 ± 0.3	5.7 ± 0.2	5.7 ± 0.3

10. Lifetimes

A. K_2^0 lifetime

(a) Combining the leptonic absolute rate of Alexander, Almeida and Crawford[30], the $\pi^+ \pi^- \pi^0$ branching ratio of Luers et al.[35] and the $\pi^0 \pi^0 \pi^0$ branching ratio of Anikina et al.[36] we calculate[31] a total rate and so obtain a lifetime $\tau_2 = 6.8 \begin{smallmatrix} +2.6 \\ -1.5 \end{smallmatrix} \times 10^{-8}$ sec.

(b) By comparison, Bardon et al.[49] obtained long ago $\tau_2 = 8.1 \begin{smallmatrix} +3.3 \\ -2.4 \end{smallmatrix} \times 10^{-8}$ sec, by attenuation with distance.

(c) Darmon et al.[50], with a heavy liquid B.C. and 15 events = 24 events minus 9 events-calculated-background find $\tau_2 = 5.1 \begin{smallmatrix} +2.4 \\ -1.3 \end{smallmatrix} \times 10^{-8}$ sec.

B. ${}_\Lambda H^4$ lifetime

Crayton et al.[51] using a Bevatron K^- beam and an emulsion stack, find $\tau({}_\Lambda H^4) = 1.2 \begin{smallmatrix} +0.7 \\ -0.3 \end{smallmatrix} \times 10^{-10}$ sec as an upper limit.

C. ${}_\Lambda H^3$ lifetime

Block et al.[52], from 41 events produced by K^- in the Helium B.C. obtain $\tau({}_\Lambda H^3) = 1.23 \begin{smallmatrix} +0.31 \\ -0.20 \end{smallmatrix} \times 10^{-10}$ sec. Dalitz and Rajasekharan point out that this lifetime depends on the spin J of ${}_\Lambda H^3$. Block et al. use their formulas to calculate $\tau(J = 1/2) = 1.78 \pm 0.06$, $\tau(J = 3/2) = 2.41 \pm 0.02 \times 10^{-10}$ sec. They normalize to the free - Λ lifetime of Block et al., which is $2.34 \pm 0.06 \times 10^{-10}$ sec. Clearly the spin J of ${}_\Lambda H^3$ cannot yet be decided.

D. K_1^0 lifetime

Two recent lifetimes are those of Golden et al.[53] from the associated production run, and of Garfinkel[54]. We list the older (and longer) values for comparison, using the table in Garfinkel's thesis[54].

$\tau(K_1^0)$ in 10^{-10} sec	Experimenters		
0.885 ± 0.025	Golden et al.[53]	Berkeley	72-inch H.B.C.
0.90 ± 0.05	Garfinkel[54]	Columbia	20-inch H.B.C.
$1.06 \begin{smallmatrix} +0.08 \\ -0.06 \end{smallmatrix}$	Eisler et al.	Columbia	
$1.15 \begin{smallmatrix} +0.40 \\ -0.25 \end{smallmatrix}$	Blemenfeld et al.	Columbia	
$0.84 \begin{smallmatrix} +0.35 \\ -0.19 \end{smallmatrix}$	Cooper et al.	Jungfraujoch	
$0.81 \begin{smallmatrix} +0.23 \\ -0.15 \end{smallmatrix}$	Brown et al.	Michigan	
1.07 ± 0.13	Boldt et al.	MIT	
0.94 ± 0.05	Crawford et al.	Berkeley	10-inch H.G.C.

E. <u>Λ-lifetime</u>

There is at present an East-West effect. This is shown in the ideogram. It does not go with long versus short chambers, at least in the West. We obtain the same values with 10-inch, 15-inch and 72-inch chambers. We also sometimes obtain shorter mean lives than is customary elsewhere (see above K_1^0 lifetimes).

We have not yet been able to discover what is wrong with the Eastern Λ lifetimes.

References

1) L. Bertanza, V. Brisson, P.L. Connolly, E.L. Hart, I.S. Mittra, G.C. Moneti, R.R. Rau, N.P. Samios, I.O. Skillicorn, S.S. Yamamoto, M. Goldberg, L. Gray, J. Leitner, S. Lichtman, and J. Westgard. See Session 4B.

2) Luis W. Alvarez, J.P. Berge, G.R. Kalbfleisch, J. Button-Shafer, F.T. Solmitz, M.L. Stevenson and H.K. Ticho. See Session 4B.

3) G.M. Pjerrou, D.J. Prowse, P. Schlein, W.E. Slater, D.H. Stork and H.K. Ticho. See Session 4B.

4) W.B. Fowler, R.W. Birge, P. Eberhard, R. Ely, M.L. Good, W.M. Powell and H.K. Ticho, Phys.Rev.Letters 6, 134 (1961).

5) B. d'Espagnat and J. Prentki, Phys.Rev. 114, 1366 (1959).

6) S. Treiman, Nuovo Cimento 15, 916 (1960).

7) A. Pais, Phys.Rev. 122, 317 (1961).

8) T.D. Lee and C.N. Yang, Phys.Rev. 109, 1755 (1958).

9) J.W. Cronin and O.E. Overseth. See Session 4B.

10) L. Gray, E. Harth, J. Leitner, J. Auman, M.M. Block, P. Gessaroli, T. Kopelman, L. Grimellini, T. Kikuchi, L. Lendinara and L. Monari, to be published.

11) E.F. Beall, B. Cork, D. Keefe, P.G. Murphy and W.A. Wenzel, Phys.Rev.Letters 8, 75 (1962).

12) R.W. Birge and W.B. Fowler, Phys.Rev.Letters 5, 254 (1960).

13) E. Boldt, H.S. Bridge, D.O. Caldwell and Y. Pal, Phys.Rev. Letters 1, 256 (1958).

14) S. Okubo, R.E. Marshak and E.C. G. Sudarshan, Phys.Rev. 113, 944 (1959).

15) J.A. Anderson, F.S. Crawford, B.B. Crawford, R.L. Golden, L.J. Lloyd, G.W. Meisner and L. Price. See Session 1B.

16) See, for instance, Ref. 10). See also the plenary talk of G. Snow for a summary.

17) B. Cork, L. Kerth, W.A. Wenzel, J.W. Cronin and R.L. Cool, Phys.Rev. 120, 1000 (1960).

18) M.M. Block, R. Gessaroli, S. Ratti, L. Grimellini, T. Kikuchi and E. Harth, to be published.

19) R.H. Dalitz and L. Liu, Phys.Rev. 116, 1312 (1959).

20) Proceedings of the 1960 Annual International Conference on High Energy Physics at Rochester, p. 726.

21) F. Crawford, M. Cresti, R. Douglass, M. Good, G. Kalbfleisch, M.L. Stevenson, and H. Ticho, Phys.Rev.Letters 2, 266 (1959).

22) P. Franzini, A. Garfinkel, J. Koren, A. Michelini, R. Plano, A. Prodell, M. Schwartz, J. Steinberger and S.E. Wolf, Bull.Am.Phys.Soc. 5, 224 (1960).

23) C. Baltay, H. Courant, W.J. Fickinger, E.C. Fowler, H.L. Kraybill, J. Sandweiss, J.R. Sanford, D.L. Stonehill and H.D. Taft, Revs.Modern Phys. 33, 374 (1961).

24) M. Ferro-Luzzi, R.D. Tripp and M.B. Watson, Phys.Rev. Letters 8, 28 (1962).

25) R.D. Tripp, M.B. Watson and M. Ferro-Luzzi, Phys.Rev. Letters 9, 66 (1962).

26) M.M. Nussbaum, R.W. Kraemer, A. Pevsner, M. Block and A. Kovacs, to be published.

27) M. Gell-Mann and A.H. Rosenfeld, Ann.Rev. Nuclear Sci. 7, 454 (1957).

28) W.H. Humphrey and R.R. Ross, UCRL-10018, January 12, 1962 (to be submitted to Phys.Rev.).

29) A. Barbaro-Galtieri, W.H. Barkas, H.H. Heckman, J.W. Patrick and F.M. Smith, Phys.Rev.Letters 9, 26 (1962).
See also Session 4B, Crawford talk.

30) G. Alexander, S.P. Almeida and F.S. Crawford, Phys.Rev. Letters 9, 69 (1962).

31) Session 4B. Crawford talk. This contains some material not included in Ref. 30).

32) R.P. Ely, W.M. Powell, H. White, M. Baldo-Ceolin, E. Calimini, S. Ciampolillo, O. Fabbri, F. Farini, C. Filippi, H. Huzita, G. Miari, U. Camerini, W.F. Fry and S. Natili, Phys.Rev. Letters 8, 132 (1962).

33) F.S. Crawford, M. Cresti, R.L. Douglass, M.L. Good, G.R. Kalbfleisch, M.L. Stevenson and H.K. Ticho, Phys.Rev. Letters 2, 361 (1959).

34) R.F. Sawyer and K.C. Wali, Nuovo Cimento 17, 938 (1960). This formula holds for any admixture of the three possible final states of 3 pions with I = 1.

35) D. Luers, I.S. Mittra, W.J. Willis and S.S. Yamamoto, Phys. Rev.Letters 7, 255 (1961).

36) M.H. Anikina, D.M. Kotliarevsky, A.A. Koslov, M.S. Dzuravleva, S.M. Mandzavidse, A.N. Mestvirishvili, D.V. Niagu, N.I. Petrov, A.M. Rosanova, V.A. Rusakov, E.O. Okonov, G.G. Tachtamishev and L.B. Chkheidse. Presented by I.A. Chuvilo, Session 4B.

37) M. Chretien, V. Fischer, H.R. Crouch, Jr., R.E. Lanou, Jr., J.T. Massimo, A.M. Shapiro, J.P. Averell, A.E. Brenner, D.R. Firth, L.G. Hyman, M.E. Law, R.H. Milburn, E.E. Ronat, K. Strauch, J.C. Street, J.J. Szymanski, L. Guerriero, I.A. Pless, L. Roesenson and G.A. Saladin, to be published.

38) J.L. Brown, J.A. Kadyk, G.H. Trilling, B.P. Roe, D. Sinclair and J.C. Vander Velde, to be published.

39) J.L. Brown, J.A. Kadyk, G.H. Trilling and R.T. Van de Walle, Phys.Rev.Letters 7, 423 (1961).

40) B.P. Roe, D. Sinclair, J.L. Brown, D.A. Glaser, J.A. Kadyk and G.H. Trilling, Phys.Rev.Letters 7, 346 (1961).

41) J.M. Dobbs, K. Lande, A.K. Mann, K. Reibel, F.J. Sciulli, H. Uto, D.H. White and K.K. Young, Phys.Rev.Letters 8, 295 (1962).

42) J.L. Brown, J.A. Kadyk, G.H. Trilling, R.T. Van de Walle, B.P. Roe and D. Sinclair, Session 4B.

43) W.E. Humphrey, J. Kirz, A.H. Rosenfeld and J. Leitner, Session 4B.

44) F. Eisler, J.M. Gaillard, J. Keren, M. Schwartz and S. Wolf, Phys.Rev. Letters 7, 136 (1961).

45) W.E. Humphrey, J. Kirz, A.H. Rosenfeld, J. Leitner and Y. Rhee, Phys.Rev.Letters 6, 478 (1961).

46) R.P. Ely, G. Gidal, L. Oswald, W. Singleton, W.M. Powell, F.W. Bullock, G.E. Kalmus, C. Henderson and F.R. Stannard, Session 4B.

47) L. Grimellini, T. Kikuchi, L. Lendinara, L. Monari and M.M. Block, Session 4B.

48) W. Becker, M. Goldberg, E. Harth, J. Leitner and S. Lichtman, to be published.

49) M. Bardon, K. Lande, L.M. Lederman and W. Chinowsky, Ann.Phys. 5, 156 (1958).

50) J. Darmon, A. Rousset and J. Six, to be published.

51) N. Crayton, D.H. Davis, R. Levi Setti, M. Raymund, O. Skjeggestad, G. Tomasini, R.G. Ammar, L. Choy, W. Dunn, M. Holland, J.H. Roberts and E.N. Shipley, Session 4B.

52) M.M. Block, C. Meltzer, S. Ratti, L. Grimellini, T. Kikuchi, L. Lendinara and L. Monari, Session 4B.

53) R.L. Golden, G. Alexander, J.A. Anderson, F.S. Crawford, B.B. Crawford, L.J. Lloyd, G.W. Meisner and L. Price. To be published.

54) A.F. Garfinkel, Thesis, Columbia University Physics Department Report Nevis 104.

Figure Captions

Fig. 1 : Longitudinal polarization of daughter from decay of unpolarized parent. The expressions in parenthesis give the decay probabilities.

Fig. 2 : Velocities and spins of Λ, decay protons and carbon scatterer, in determining α_Λ.

Fig. 3 : Behaviour of parent and daughter polarization under time reversal.

Fig. 4 : Scattering analyisis of β.

Fig. 5 : Polarizations of Λ and proton in pure S-wave and pure P-wave Λ-decay.

Fig. 6 : Possible failure of the $\Delta I = \frac{1}{2}$ rule in Σ-decay. The two representations of the amplitude N_0 correspond to the present ambiguity for the S/P ratios in the three decays.

Fig. 7 : Ideogram of 14 experiments on the mean life of lambda.

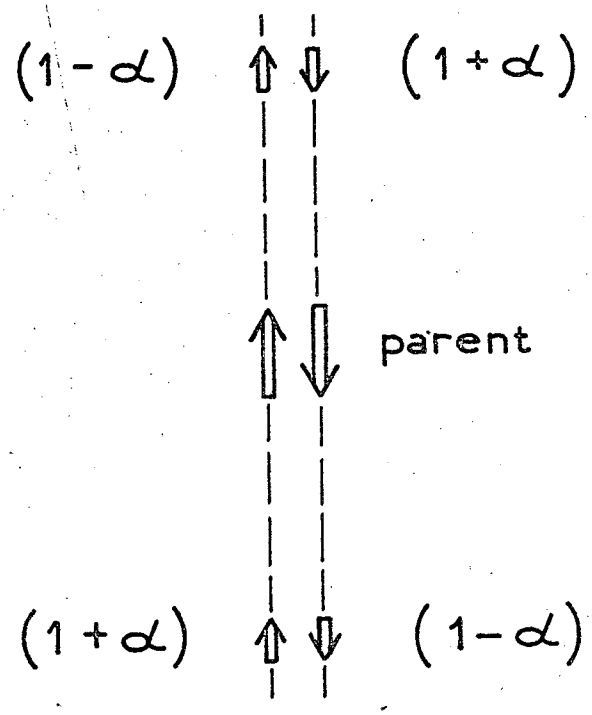


Fig. 1

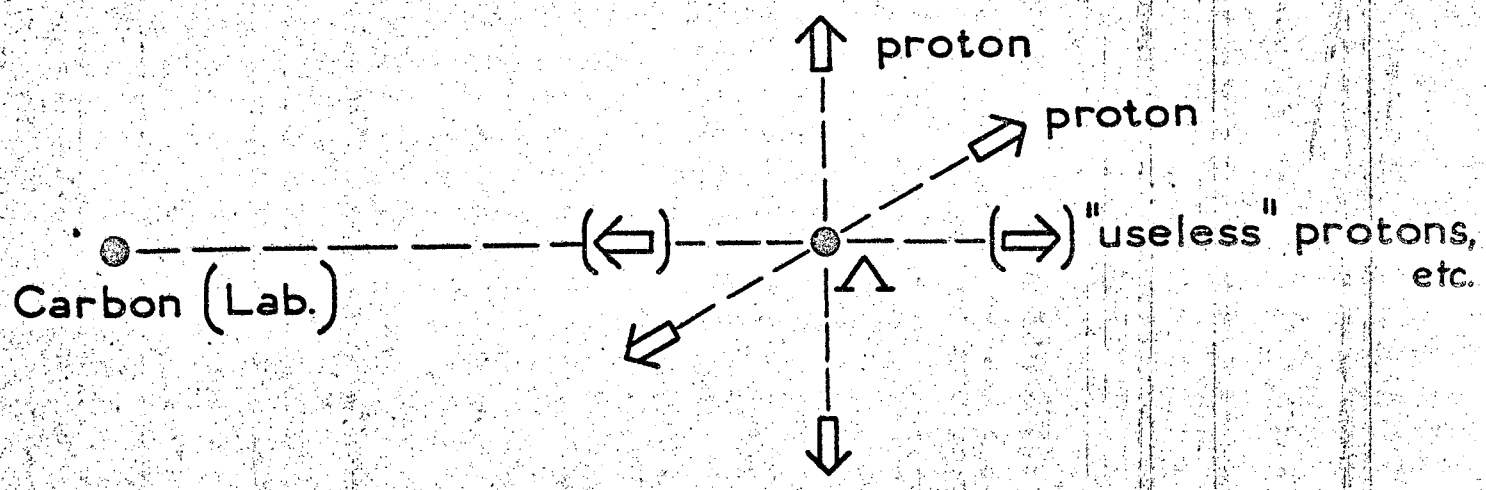


Fig. 2

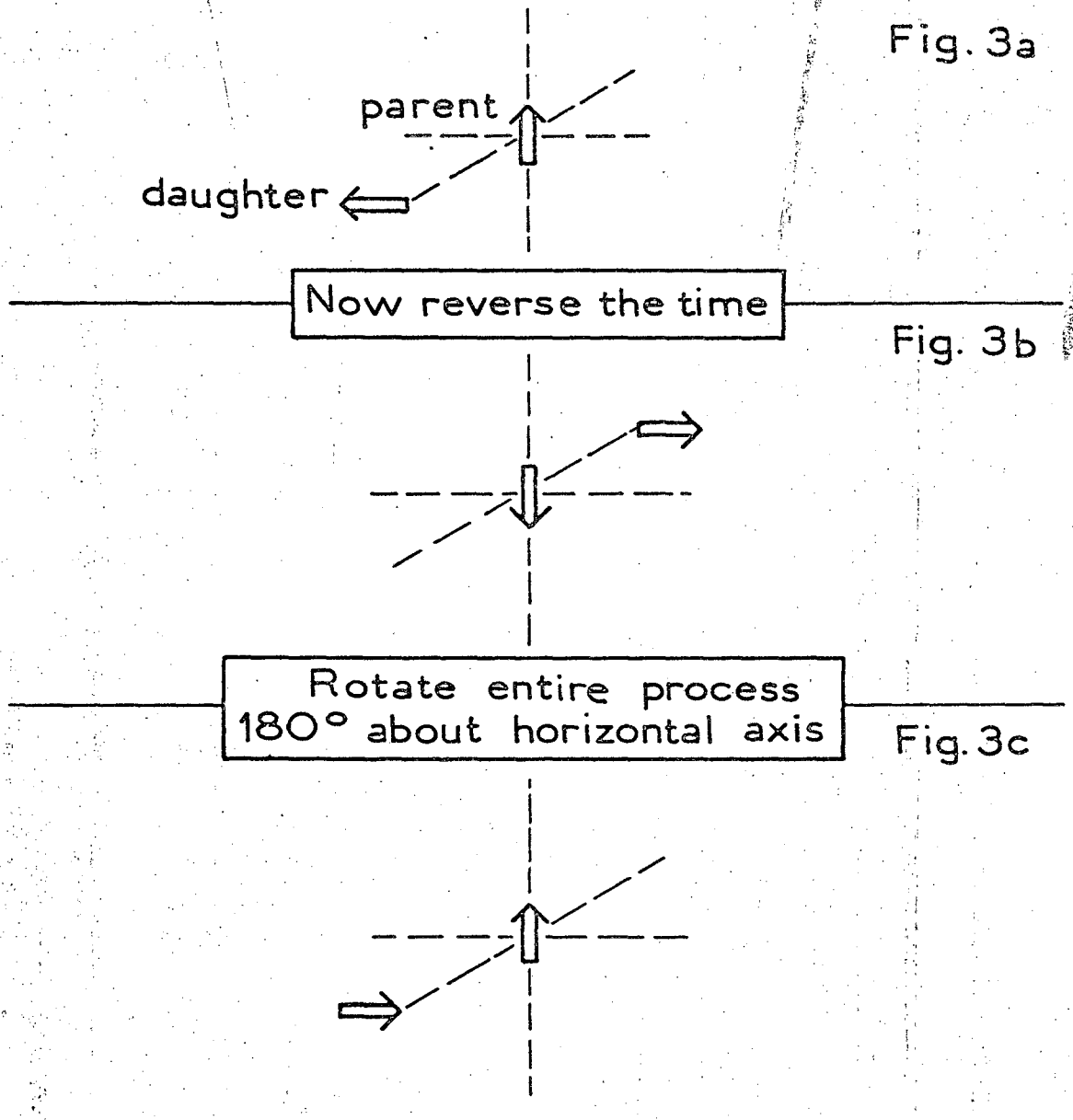


Fig. 3a

Fig. 3b

Fig. 3c

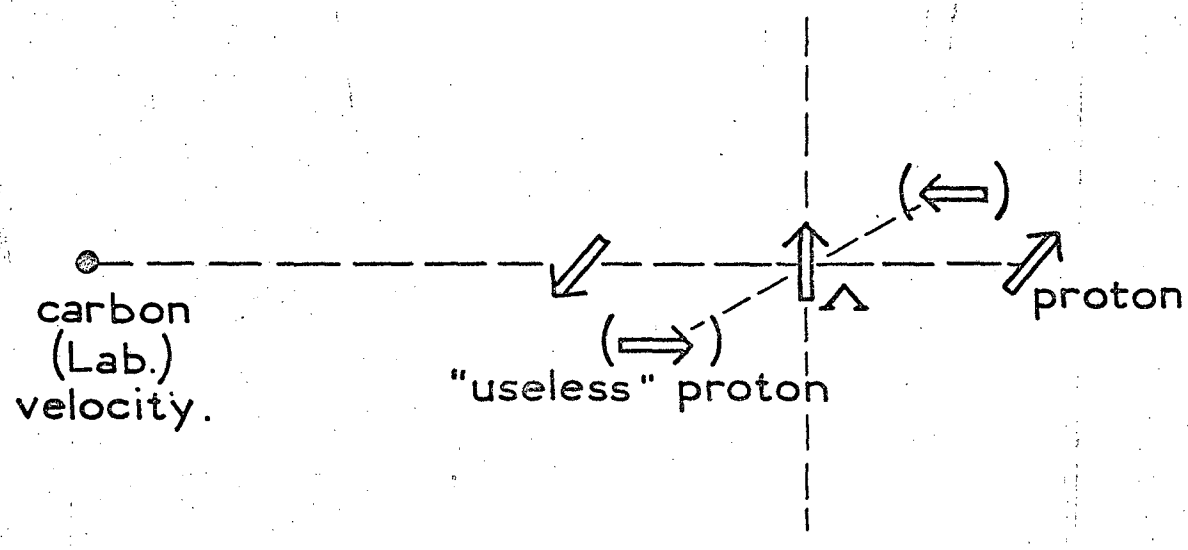


Fig. 4

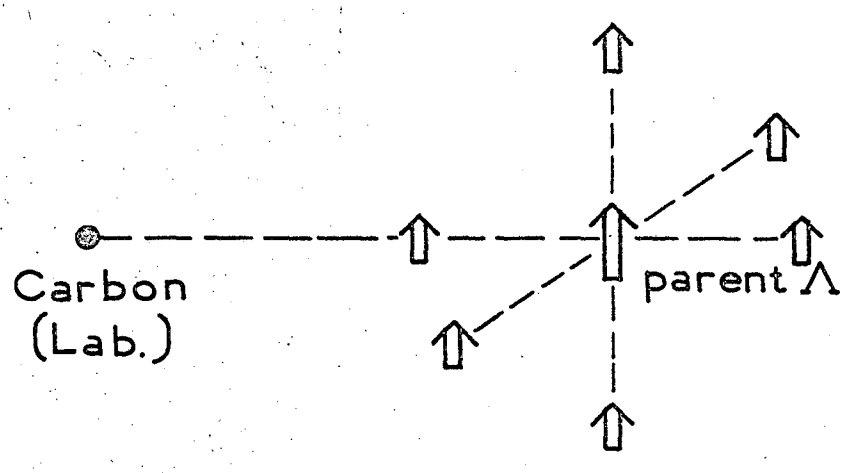


Fig. 5a
Pure S-wave decay

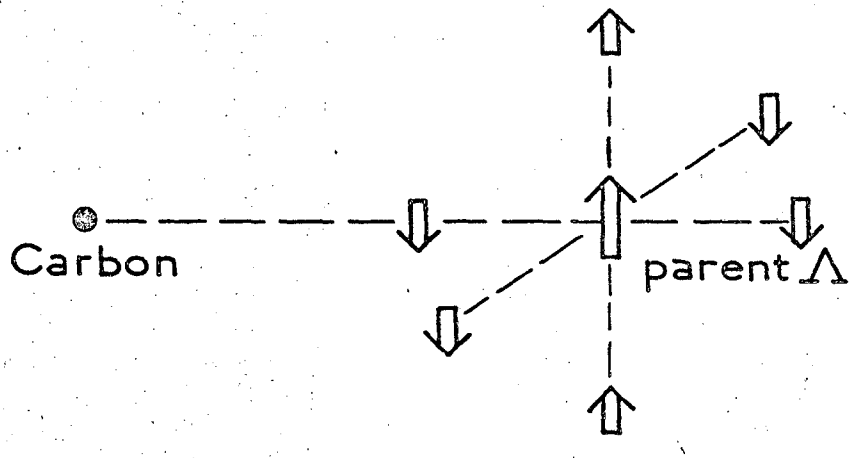


Fig. 5b
Pure P-wave decay

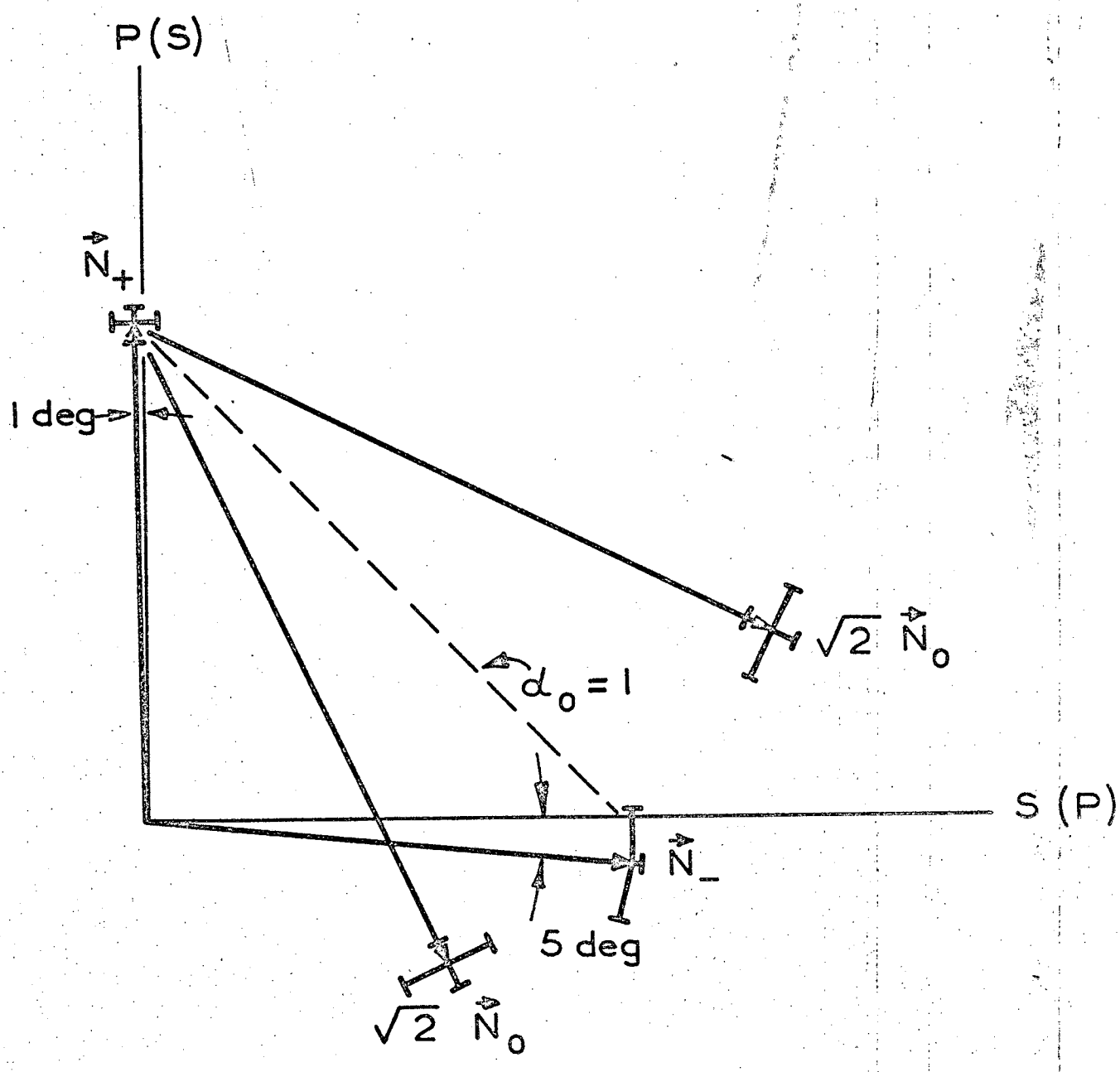
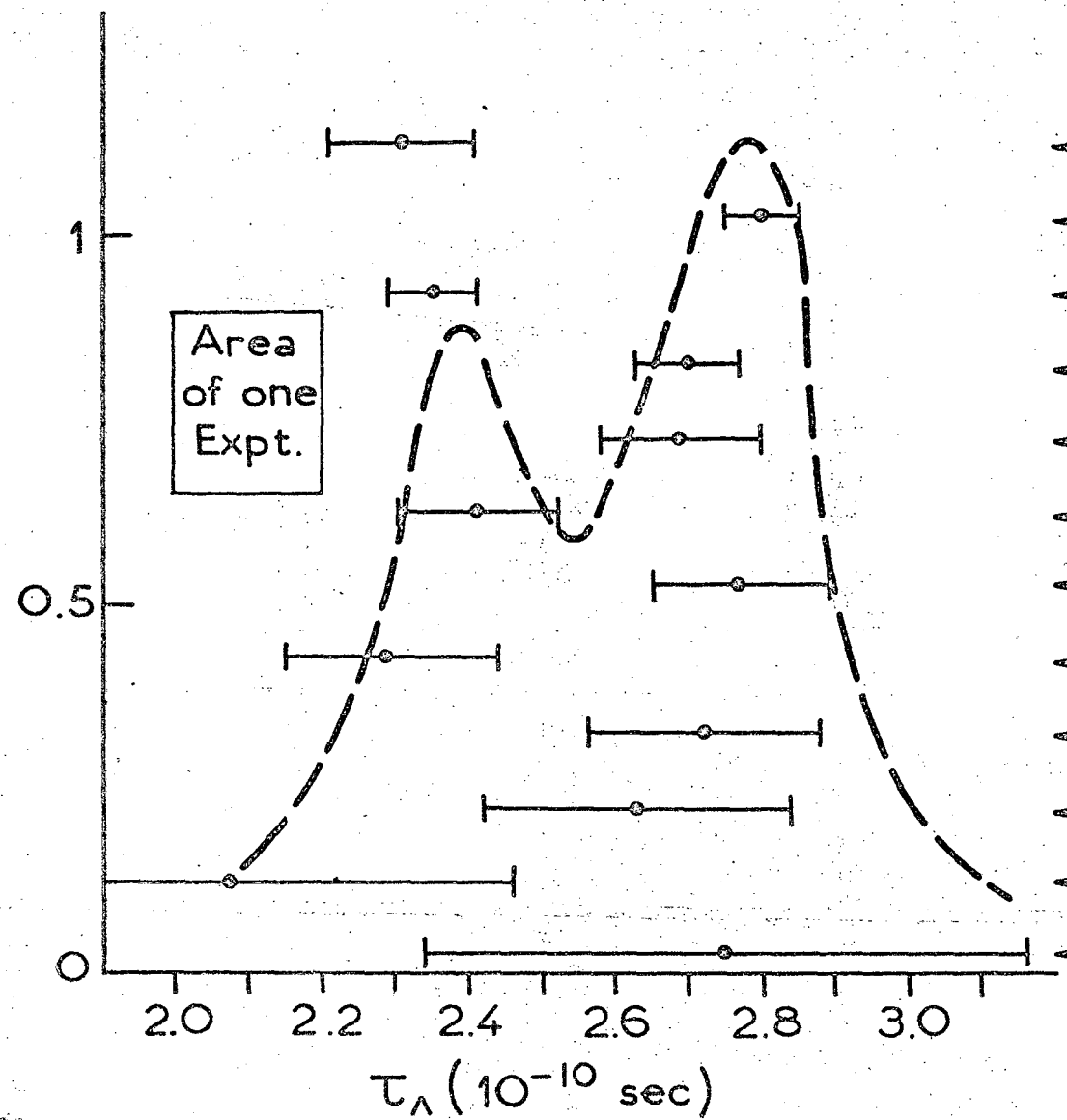


Fig. 6



Experiment	Number of Events
M. Kreisler & J. Cronin, CERN, 1962, This expt. not included in ideogram (received later)	2250
Golden et al. (LRL), CERN, 1962	2483
Auman et al. (Northwestern) CERN, 1962	1800
Murray et al. (K72, LRL, unpubl.)	2500
W.E. Humphrey (LRL), Thesis, 1962	799
A.F. Garfinkel, Nevis 104, 1962	900
J.P. Berge (LRL), Thesis, 1962	920
Columbia, Pisa, Bologna, CERN 1958.	
Crawford et al., 1958, U.C.R.L. 8030	825
Boldt, Caldwell, Pal, P.R. Lett. 1, 148 (1958)	
Michigan, CERN, 1958	
Columbia, CERN, 1958	

Fig. 7

Hyperon Muonic Decays.

Branching Fractions, f(%)	$\Sigma^-\mu^-$	$\Sigma^+\mu^+$	$\Lambda\mu^-$	Electronic decay values[a] (Listed for comparison) Σ^-e^-	Σ^+e^+	Λe^-
1. Predicted by Feyman and Gell-Mann[b], f_{FGM}	2.5	1.01[c]	0.3	5.6	2.3[c]	1.6
2. Experimental, published to date, f_{exp}	<0.2[d]	0.3[d,e]	0.1[d,f]	see row (5)		
3. f(μ) expected by scaling f(e) data proportionally to phase space	0.05	0.04	0.04			
4. f(μ) reported in this note	0.065	0.15	0.05			
5. All available data[g]	<0.05	0.1	0.03	0.1[h]	<0.1	0.2[h]
Detection Efficiency (%)						
6. By scanning only	19	19×2[i]	30×$\frac{3}{2}$[j]	28	2×28	---
7. On measured events	20	20×2[i]	40×$\frac{3}{2}$[j]	33	2×33	70

[a] See reference 2.

[b] See references 1 and 7.

[c] From phase space. However, $\Sigma^+\mu^+$ and Σ^+e^+ decays were formerly believed to be forbidden by the $\Delta S = \Delta Q$ rule.

[d] Survey by D. A. Glaser, in the Proceedings of the Ninth Annual Conference on High-Energy Physics, Kiev, 1959 (Academy of Sciences, Moscow, 1960), p. 260.

[e] Barbaro-Galtieri et al.[4]

[f] Eisler et al. See reference 4.

[g] These fractions represent only the samples known to us, and especially examined for muonic decays. In other experiments comparable numbers of hyperons have been found. Since no uniform procedures were used, efficiences for finding such events are hard to evaluate, so these experiments were not included in this summary.

[h] In addition to the Σ^-e^- and Λe^- events reported in (2), Bhowmik et al. report one Σ^-e^- and two Λe^+ events in a small sample of hyperon decays (Nuovo cimento 21, 567 and 1066 (1961).

[i] The factor 2 is due to the $\Sigma^+ \to p + \pi^0$ decay mode which will not be confused with $\Sigma^+ \to n + \mu^+ + \nu$.

[j] The factor 3/2 corrects for the neutral decay mode of the normal Λ decay.