

The following paper "Possible Violation of $\Delta S = \Delta Q$ "
is the synthesis of two talks given respectively by
J. Steinberger in SESSION 1 and by A. Plano in SESSION 6 of the
Conference.

Possible Violation of $\Delta S = \Delta Q$ *

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The question of the possible existence of $\Delta S = -\Delta Q$ currents is of substantial theoretical interest. There are at present, to our knowledge, two experimental results which would require such currents: the observations of Fry et al on the time distribution of electronic K^0 decay,¹ and the exhibition by Barkas et al of an example of the decay $\Sigma^+ \rightarrow \mu^+ + \bar{\nu} + n$.² We report here briefly experiments designed to check these two results.

In the experiment of Fry et al the K^0 mesons were produced in the heavy liquid chamber by charge exchange of an incident K^+ beam, and the electronic K^0 decays were detected by their appearance. In our case the K^0 mesons are produced in the capture of antiprotons stopping in the Columbia-BNL 30" hydrogen bubble chamber, and 3 body decays are selected by kinematic analysis after measuring all V's. To date 2700 V^0 were measured, and this

represents approximately one-third of the data which we hope to have. Of these 2300 were accepted as $K_1^0 \rightarrow 2\pi$ decays, and 33 as three body decays, all within the fiducial region. The 2300 $K_1^0 \rightarrow 2\pi$ decays correspond to a K^0 flux of 7500. The actual decay mode ($e^\pm + \pi^\mp + \nu$, $\mu^\pm + \pi^\mp + \nu$, $\pi^+ + \pi^- + \nu$) is known for some of the 33 events, but in general it is not. None of the 33 decays are consistent with three π decay.

The association of each K^0 with a particular stopping \bar{p} is clear, there are no ambiguous events in this respect. The momentum of the K^0 is known in 60% of the cases from the production vertex, in one-half of the remaining cases from the decay, and in the remainder there are two possible momenta and we cannot distinguish. These events were assigned with weight of one-half to each of the two momenta.

The decay times of these events are plotted in Fig. 1. The expected distribution is of the form (1) $F(t) = \alpha e^{-t/\lambda_1} + e^{-t/\lambda_2}$ where λ_1 and λ_2 are the K_1^0 and K_2^0 mean lives, respectively. α is the ratio of the leptonic decay probabilities of the K_1^0 and K_2^0 . In terms of x , the ratio of $\Delta S = \Delta Q$ violating to non-violating amplitudes, $\alpha = \left| \frac{1+x}{1-x} \right|^2$; if $\Delta S = \Delta Q$, then $x = 0$ and $\alpha = 1$. The previous results are $\alpha = 12 \pm 6$,¹ and $\alpha = 6 \pm 4$.³

Before comparing the experimental result of Fig. 1 with theoretical distributions of the form (1) we must first:

- a) Multiply this distribution with a geometrical efficiency factor derived from the dimensions of the fiducial regions and the momentum distribution of the observed $K_1^0 \rightarrow 2\pi$ events.

b) Add to the distribution the probability for the radiative $K_1^0 \rightarrow \pi^+ + \pi^-$ decay. The probability of inner bremsstrahlung is calculated according to the relation ⁴

$$P(k_0) = \frac{2\alpha}{\pi} \int_{k_0}^{k_{\max}} \frac{dk}{k} \left(1 - \frac{2k}{m_K}\right) \frac{\beta}{\beta_{\pi\pi}} \left(\frac{1+\beta^2}{2\beta} \ln \frac{1+\beta}{1-\beta} - 1 \right)$$

where $P(k_0)$ is the probability for decay in $\pi + \pi + \gamma$ with photon energy in excess of k_0 , m_K is the K^0 mass, β is the velocity of the pions in their rest system, and $\beta_{\pi\pi}$ is the same velocity for the nonradiative decay. For k_0 we take 50 MeV, our estimate for the average energy which must be radiated before an event is rejected as $K_1^0 \rightarrow \pi^+ + \pi^-$. $P(50 \text{ MeV}) = 3 \times 10^{-3}$. For the mean lives τ_1 and τ_2 we use 10^{-10} and 6×10^{-8} sec, respectively. On this basis we find that the data of Fig. 1 are consistent with no $\Delta S = \Delta Q$ violation. The data do not exclude, however, a value of α not exceeding 3, corresponding to a $\Delta S = -\Delta Q$ amplitude not exceeding one quarter of the $\Delta S = +\Delta Q$ amplitude. The results disagree with the earlier results.¹

The second experiment deals with the leptonic Σ^\pm decays:

$$\Sigma^\pm \rightarrow n + l^\pm (\mu^\pm) + \nu .$$

We have measured and analyzed the momenta of the secondaries of 6800 non protonic Σ^+ decays and 2500 Σ^- decays, for Σ 's produced by the capture of K^- mesons stopped in hydrogen. In this way we find systematically secondaries of momentum incompatible with the dominant π decay. The secondaries so selected are gap counted. Electrons and positrons can in this way be

distinguished with substantial confidence from pions and muons, although these latter cannot be separated themselves by this technique. In the case of the Σ^- we find 8 electronic decays (see Fig. 2) as well as 1 radiative pionic decay, and 2 which could be pionic or muonic. From this we may deduce a branching ratio

$$R \frac{\Sigma^- \rightarrow e^- + \pi + \nu}{\Sigma^- \rightarrow \pi^- + n} = \frac{8}{2500 \times 0.87} = 3.7 \pm 1.3 \times 10^{-4}$$

where the factor 0.87 is the fraction of the electronic phase space within the accepted momentum interval.

In the case of the Σ^+ (Fig. 3) we have 15 abnormal decays in 6800 $\Sigma^+ \rightarrow \pi^+ + n$ decays. The gap count of these is shown in Fig. 4. One of the events is consistent with being a positron, the others are consistent with being either muons or pions. Statistically the positron event is 3 standard deviations from the μ , and 4 standard deviations from the π line. Since we have 1 μ and 13 π 's in this sample[†] the statistical probability to have one muon or pion with the observed or greater gap count is $\sim 2.5 \times 10^{-3}$. We can multiply this by ~ 2 since the CERN group

[†] It is not possible experimentally to separate the sample into μ and π . The non leptonic source of μ 's is π decay in a short distance. We estimate that this decay should be noticeable for pion path lengths in excess of 1.5 mm. This would result in 1 muon for the whole sample. This is not inconsistent with the gap length distribution of Fig. 3.

has observed comparable group of Σ^+ decays without an example of leptonic decay. So considering only the statistical effects, the probability that the apparent e^+ is either a π or μ with abnormal gap count is quite small: $\sim 0.5\%$. It is not easy to estimate the possibility of systematic error in the gap count, but it cannot be excluded. We can only say that the event has received a substantial amount of attention, and we are continuing a systematic study of gap count for tracks of known mass. Some of the results so far obtained are shown in Fig. 5. At this time we are not aware of any inadequacies in our technique.

If the event is accepted it would lead, on the basis of our data alone, to a ratio for the decays $\frac{\Sigma^+ \rightarrow e^+ + n + \nu}{\Sigma^- \rightarrow e^- + n + \nu}$

$$R = \frac{1 \times 2500}{6800 \times 8} = 0.05 .$$

If we add also the null result of CERN based on a sample roughly equivalent to ours[‡] (the Barkas event is not a positron), the result is roughly $R \approx 0.025$. In any case the ratio should not be more than ~ 0.1 with good confidence.

The implications for $\Delta S = \Delta Q$ are somewhat muddy. We can say that at most the $\Delta S = -\Delta Q$ amplitudes are substantially smaller than the $\Delta S = \Delta Q$ amplitudes for both decays. For K^0 we have no positive evidence that $\Delta S = \Delta Q$ is violated. For

[‡] The sample is in fact much larger, but the detection efficiency for electronic decays is smaller, so that the effective sample is roughly the same.

Σ^+ decay there is some evidence, but one would like to see more.

We append an unrelated result also obtained in this experiment, namely, the rate for the radiative decay $\Sigma^\pm \rightarrow \pi^\pm + n + \gamma$. The theoretical expectation for S-wave decay into the photon momentum interval dk is:⁵

$$\frac{dP}{dk} = \frac{\alpha}{\pi} \frac{dp}{k} \frac{p}{p_0} \left\{ \ln \frac{1+\beta}{1-\beta} - 2\beta \right\}$$

where p is the pion momentum in the Σ rest frame, p_0 is the same for nonradiative decay, and β is the pion velocity.

The experimental cutoff for k is 15.5 MeV. We expect then

$$\int_{k_{\min}}^{k_{\max}} P(k) dk \times 9300 = 10 \text{ events}$$

Seventeen events have in fact been observed, but we must subtract a background of 1.5 events for $\pi \rightarrow \mu$ decay as explained in the foregoing, and perhaps from 3 to 5 events from those events in the main nonradiative decay which must statistically be expected to have a multiple scattering error of more than 20 MeV. We present this information, because very little experimental information on this type of process seems to exist.

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- 3 G. Alexander, S. P. Almeida, and F. S. Crawford, Jr., *Phys. Rev. Letters* 9, 69 (1962).
- 4 We wish to thank Dr. J. Bjorken for help in obtaining this result.
- 5 We wish to thank Drs. P. Beg and R. Friedberg for help in obtaining this result.

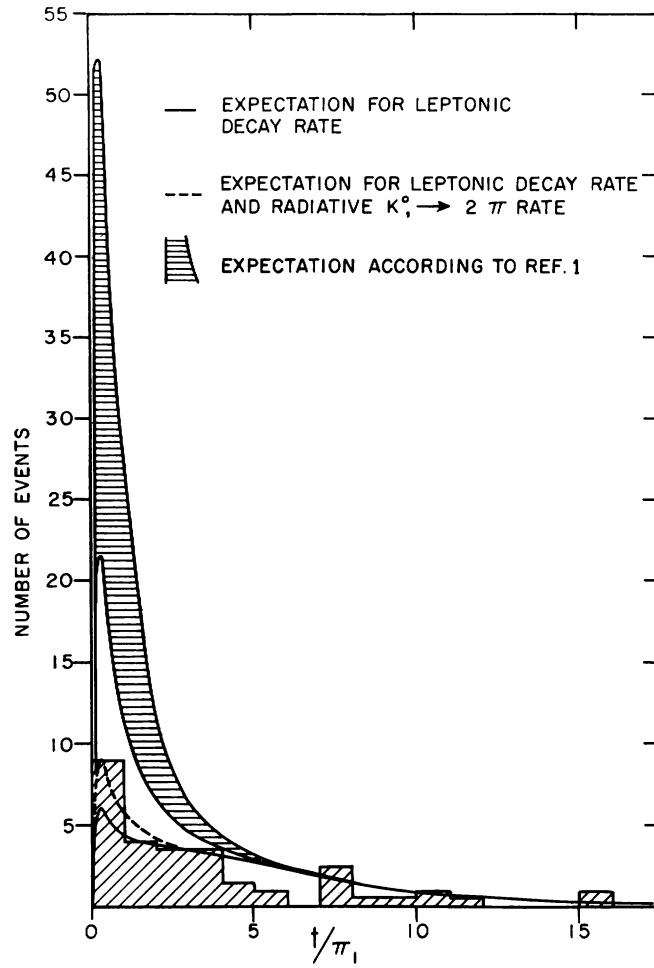


Fig. 1 - Time distribution of the three body K^0 decay events.

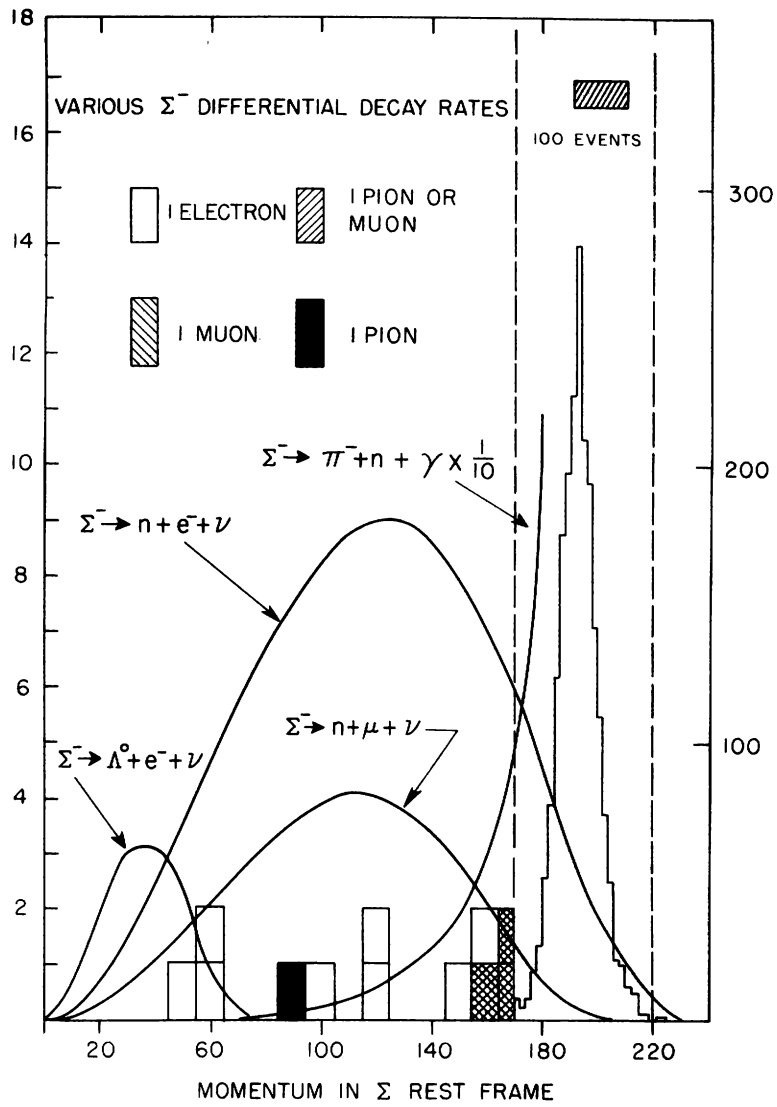


Fig. 2 - Momentum distribution of the secondaries of Σ^- decay. The main peak contains 2500 events.

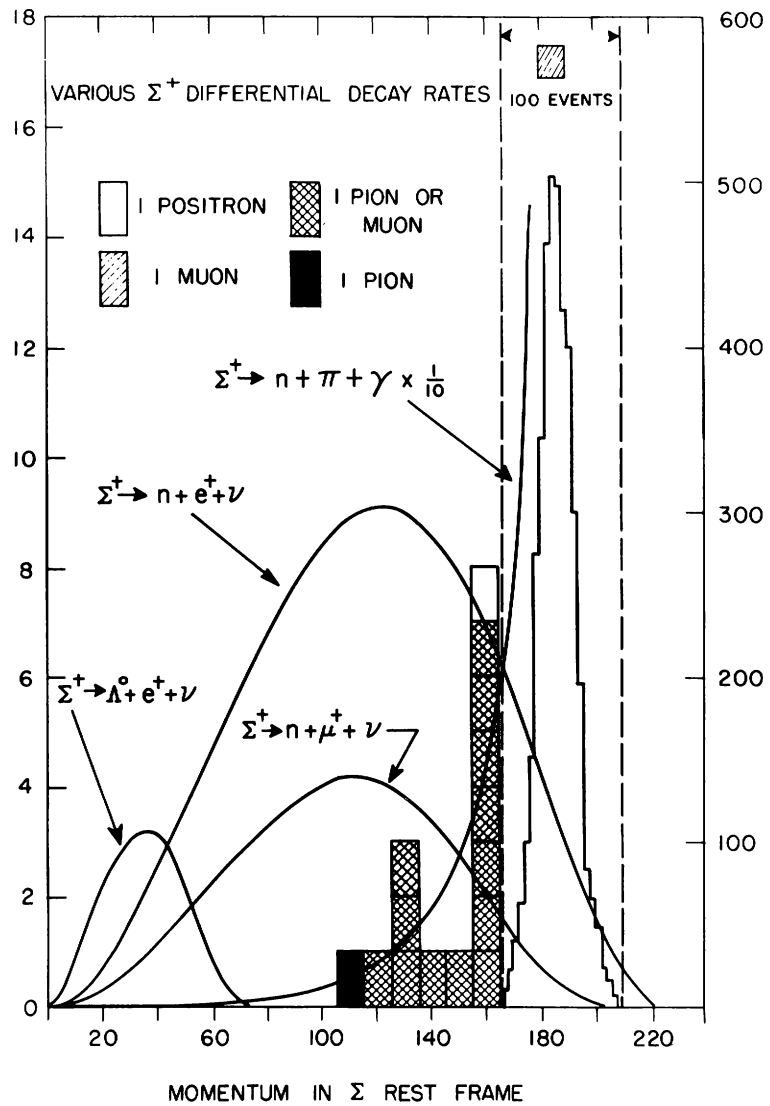


Fig. 3 - Momentum distribution of the secondaries of Σ^+ decay. The main peak contains 6800 events.

GAP COUNTING DISTRIBUTION FOR EVENTS
 WITH $P_{cm} < 166$ Mev
 Σ^+ DECAY

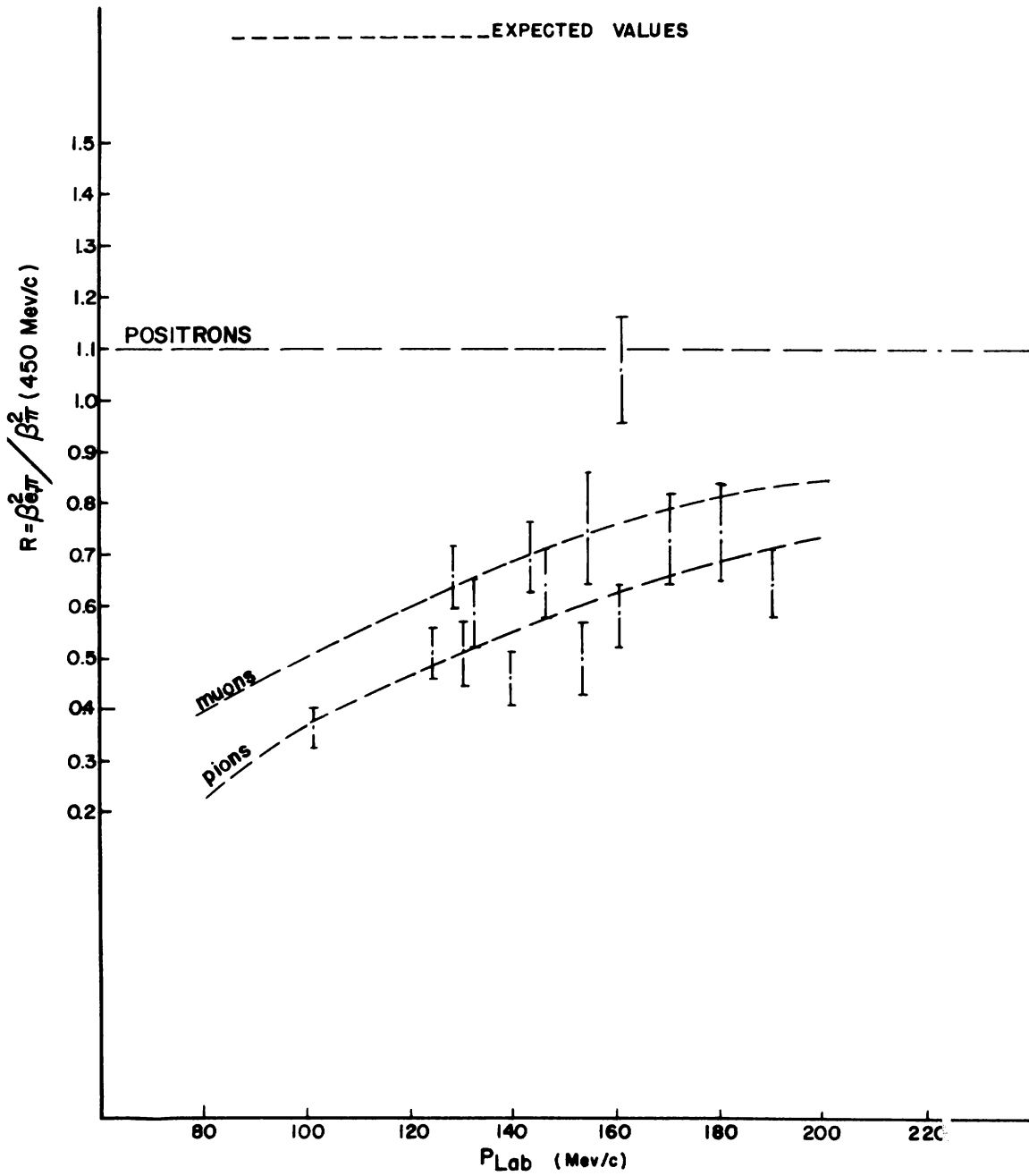


Fig. 4 - Gap length counts for the 15 Σ^+ decays of anomalous momentum.

DISTRIBUTION OF $R = \beta_{e,\pi}^2 / \beta_{\pi}^2$ (450 Mev/c)

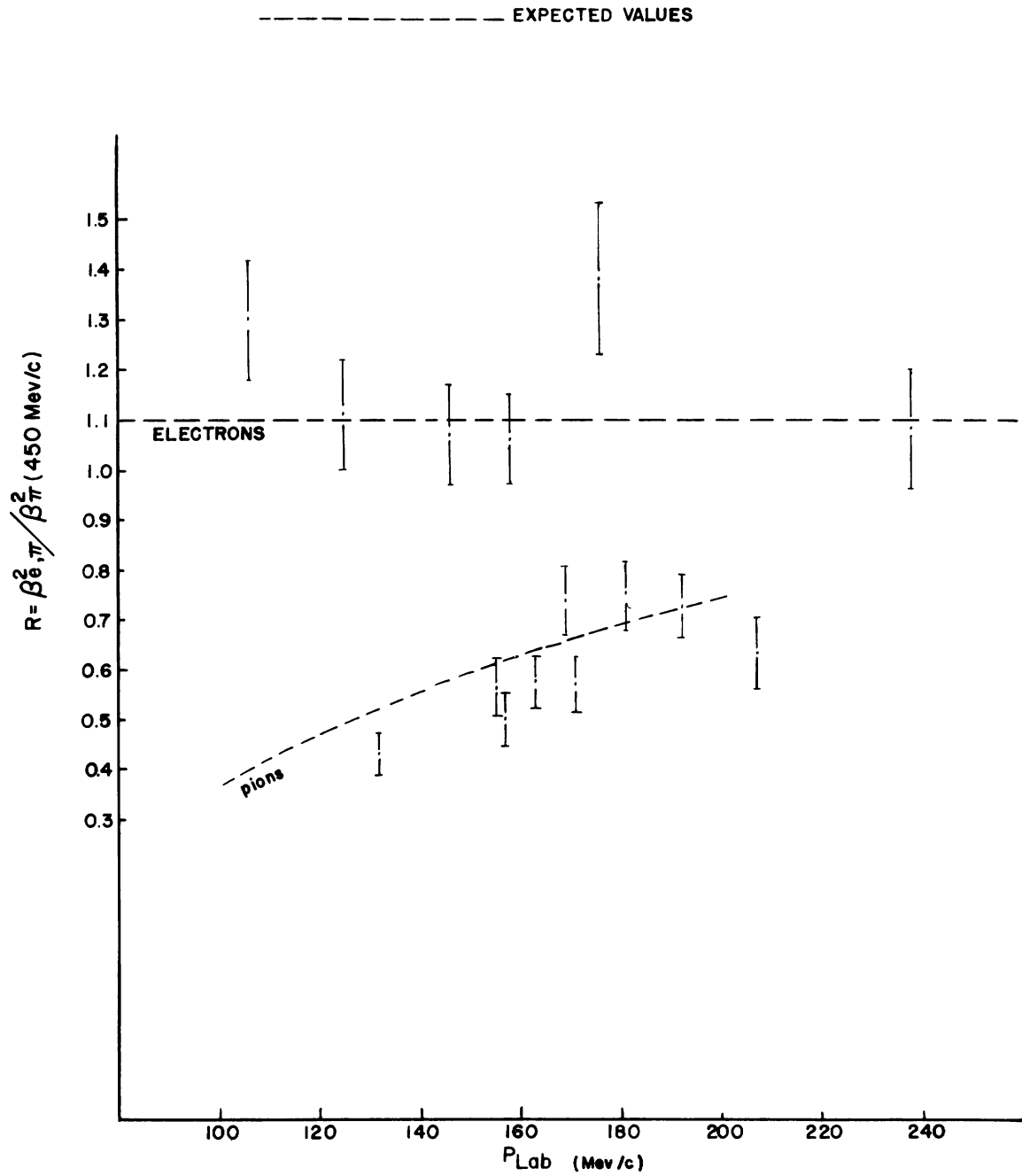


Fig. 5 - Gap length counts for several tracks known to be electrons or to be pions.