Title
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Publication Date
1963-09-16

UCRL-11018

University of California

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Berkeley, California

International Conference on Fundamental Aspects of Weak Interactions.

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Contract No. W-7405-eng-48

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About six months ago, Camerini, Fry, and Gaidos invented a beautiful method for determining the sign of $m(K_1^0) - m(K_2^0)$.[1] This method differs from all previous suggestions in one very important respect; it leads to a performable experiment.

In our experiment the method works as follows. At time $t = 0$ a K^0 is created in the 72-inch hydrogen bubble chamber, via the reaction

$$\pi^- + p \rightarrow \Lambda + K^0 . \quad (1)$$

At time t the neutral kaon has become a superposition of K^0 and $\bar{K}^0$, with amplitudes whose magnitudes depend on the K_1 and K_2 lifetimes, and whose relative phase depends on $(m_1 - m_2)t$.[1] (The formula is well known, and we need not write it down here.) Thus the relative phase of the K^0 and $\bar{K}^0$ components is known provided $m_1 - m_2$ is known. At time t this superposition scatters elastically from a proton. The K^0 part of the wave has its phase shifted by the elastic scattering phase shaft in the process

$$K^0 + p \rightarrow K^0 + p . \quad (2)$$

The $\bar{K}^0$ part has its phase shifted by the process

$$\bar{K}^0 + p \rightarrow \bar{K}^0 + p . \quad (3)$$

If we know the scattering phase shifts for processes (2) and (3) and know $m_1 - m_2$, then, after the scattering, we still know the relative phase of the K^0 and $\bar{K}^0$ parts of the wave. We now find the K_1^0 projection of the superposition, by detecting the decay

$$K_1^0 \rightarrow \pi^+ + \pi^- . \quad (4)$$

The overall rate (as a function of t) contains terms in both $\sin (m_1 - m_2)t$ and $\cos (m_1 - m_2)t$.[1]

1. U. Camerini, W. F. Fry, and J. Gaidos, Nuovo Cimento 28, 1096(1963).

In our experiment we have found 27 events of the type just described. The K^0 momenta lie between 200 and 900 MeV/c, as is shown in Fig. 1. We accept only the 18 events with K^0 momenta between 300 and 600 MeV/c, because only in this momentum interval are we sure that the phase shifts for reactions (2) and (3) are known well. For reaction (2) we use the phase shifts of Chinowsky, Goldhaber, Goldhaber, Lee, O'Halloran, Stubbs, Slater, Stork, and Ticho, as summarized in the thesis of Wonyong Lee.[2] These were obtained from experiments in the 15-inch hydrogen bubble chamber, involving $K^+ + p \rightarrow K^+ + p$, and $K^+ + n \rightarrow K^0 + p$ in deuterium between 350 and 800 MeV/c. We have extrapolated their results to 300 MeV/c.

The phase shifts for reaction (3) were obtained from a complete analysis of K^--p interactions between 250 and 513 MeV/c, by Watson, Ferro-Luzzi, and Tripp, using data from the 15-inch chamber.[3] Their results can be extrapolated with confidence to 600 MeV/c, but not farther than that. (Above 600 MeV/c one is approaching the 1660-MeV resonance, which has the quantum numbers of reaction (3). This is shown in Fig. 1, where we have included a Breit-Wigner curve corresponding to the 1660-MeV resonance.)

For the 18 events between 300 and 600 MeV/c we proceed as follows. For each event we use the information on the K momentum and on the scattering angle in reaction (2) + (3). This yields the phase shifts. For a given value of $m_1 - m_2$ (including the sign) we can then construct a normalized curve of betting odds versus the time t when the scattering occurred, between $t = 0$ and T, where T is the potential time (maximum possible value of t) and is different for each event. We then add the 18 curves together to obtain an expected time distribution for the 18 events. The distribution depends on $m_1 - m_2$. [In adding the individual curves together we lose information as to which event goes with which curve, and thus we lose the (possible) opportunity to obtain very large betting odds based on one or two very favorable scatterings. On the other hand, we are less at the mercy of fluctuations; each of the 18 events has equal weight.]

We already believe that the magnitude $|m_1 - m_2|$ is in the neighborhood of 1.6 natural units. (Our preliminary value of $|m_1 - m_2|$, based on entirely different data, is included in the summary talk of W. F. Fry.) We therefore first compare our data with the expected time distributions for $m_1 - m_2 = -1.6$ and for $m_1 - m_2 = +1.6$. This comparison is shown in Fig. 2 for one set of K^0-p phase shifts, and in Fig. 3 for another set.[2] It is clear that -1.6 is highly favored, i.e., $m_2 > m_1$.

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2. Wonyong Lee, Lawrence Radiation Laboratory Report UCRL-9691, May 19, 1961.

3. Mason B. Watson, Massimiliano Ferro-Luzzi, and Robert D. Tripp, Lawrence Radiation Laboratory Report UCRL-10542, Jan. 15, 1963, and private communication from Tripp.

We next allow $m_1 - m_2$ to vary continuously from -2.5 to + 2.5 and plot the relative-likelihood function. This is shown in Fig. 4, for the "Fermi" set of phase shifts corresponding to Fig. 2. We see that this likelihood function peaks at -1.4. (It also starts to rise towards a "first harmonic" at -2.8. We believe that the harmonics will be suppressed when we have included all the information!)

In order to go from a likelihood ratio to betting odds, we have performed Monte Carlo experiments in which we distribute 18 events according to one of the probability distributions of Figs. 2 and 3, and then calculate likelihood ratios in the same way as in the actual experiment. In this way we find betting odds of about 5000/1 against $m_1 > m_2$, using the Fermi set of K^0-p phase shifts (Fig. 2), and about 1000/1 using the Yang set (Fig. 3).

Our result, $m_2 > m_1$, is still preliminary, for the following reasons. First, we have not yet tried varying the phase-shift solutions within their expected errors. Second, there are other phase-shift solutions that include D wave for both K^0 p and $\bar{K}^0$p scattering.[2,3] We have not yet tried these solutions.

Once we are certain of the sign of $m_1 - m_2$, we hope to be able to turn the problem around and determine which set of phase-shifts fits best.

Fig. 1

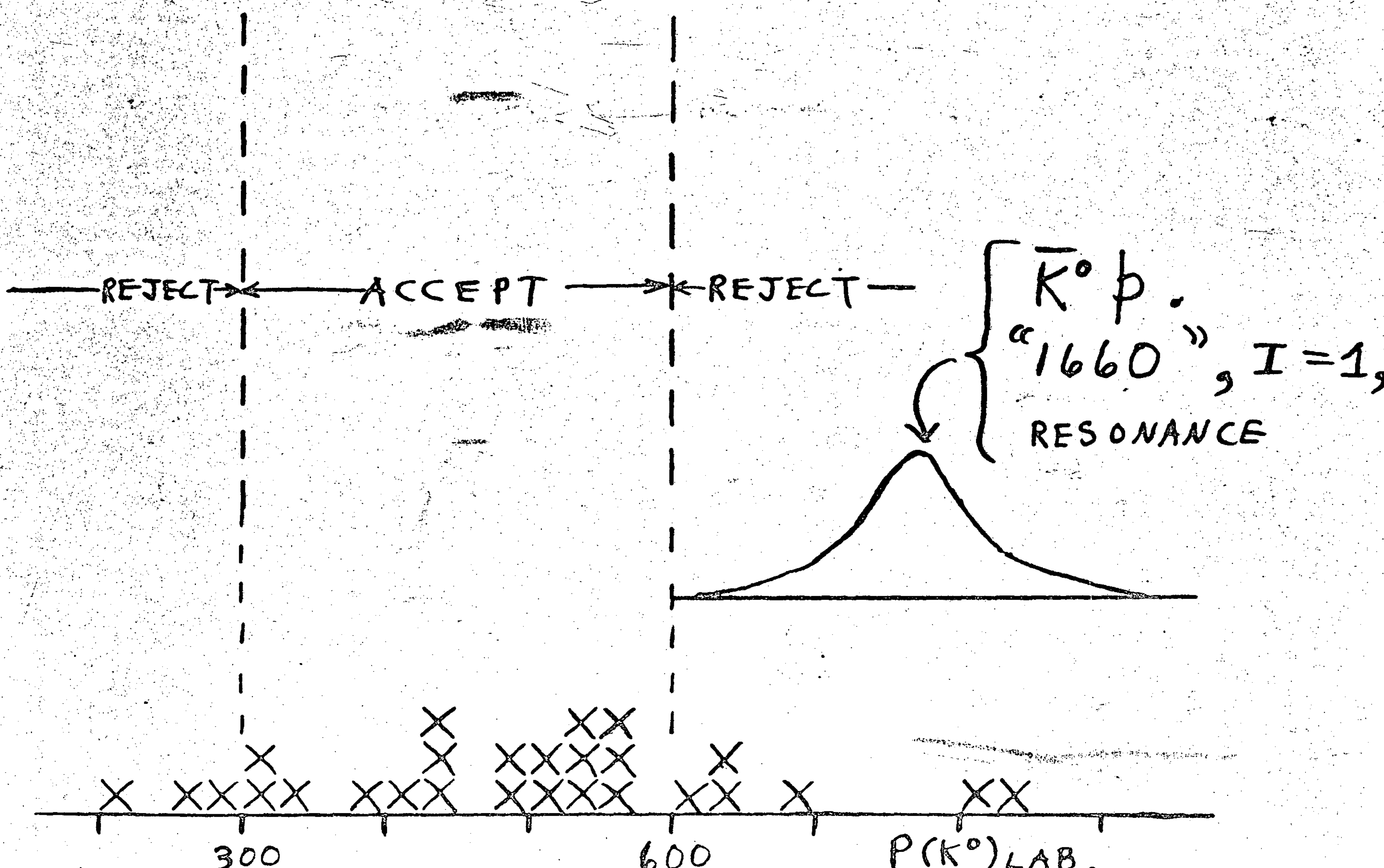
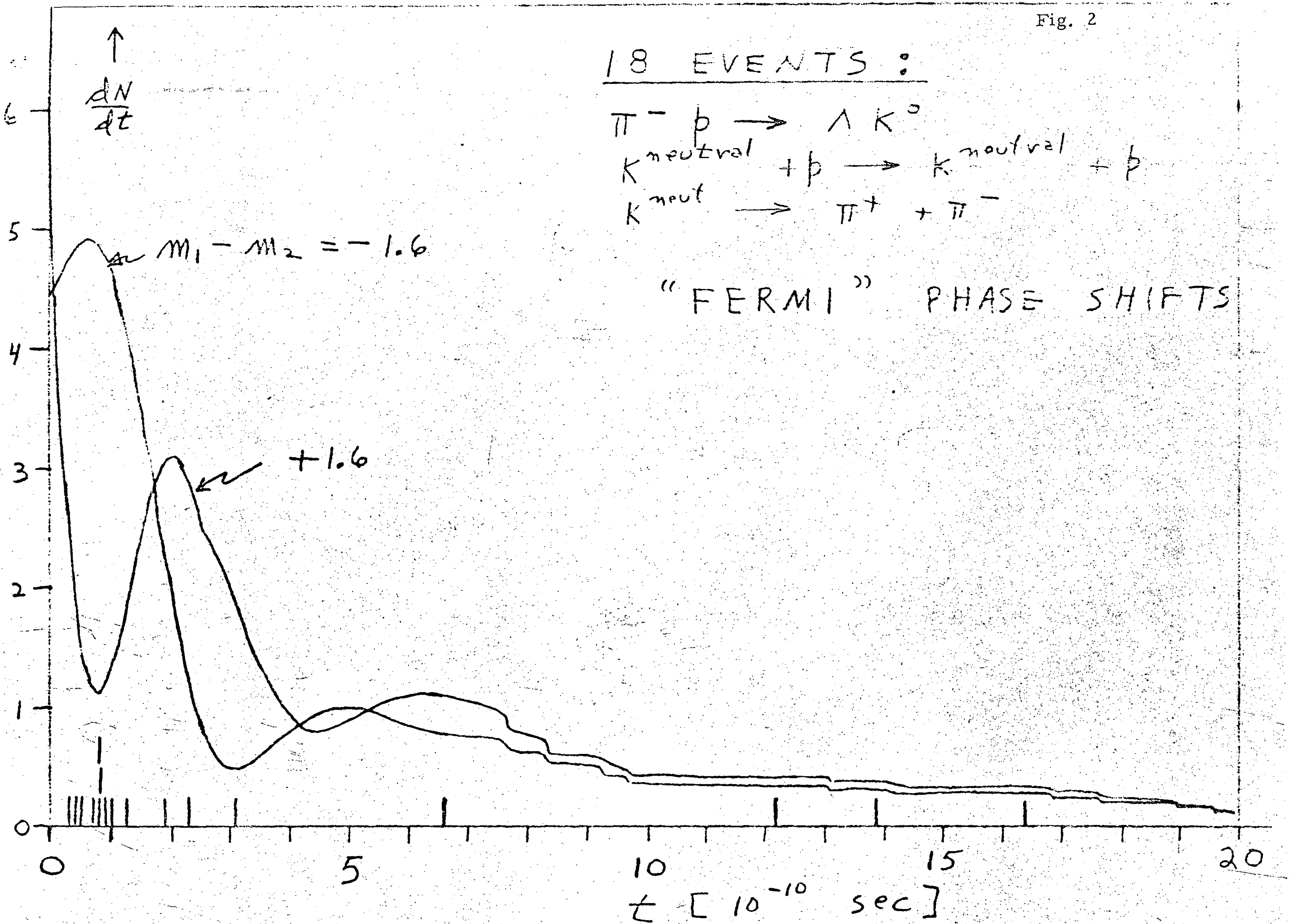
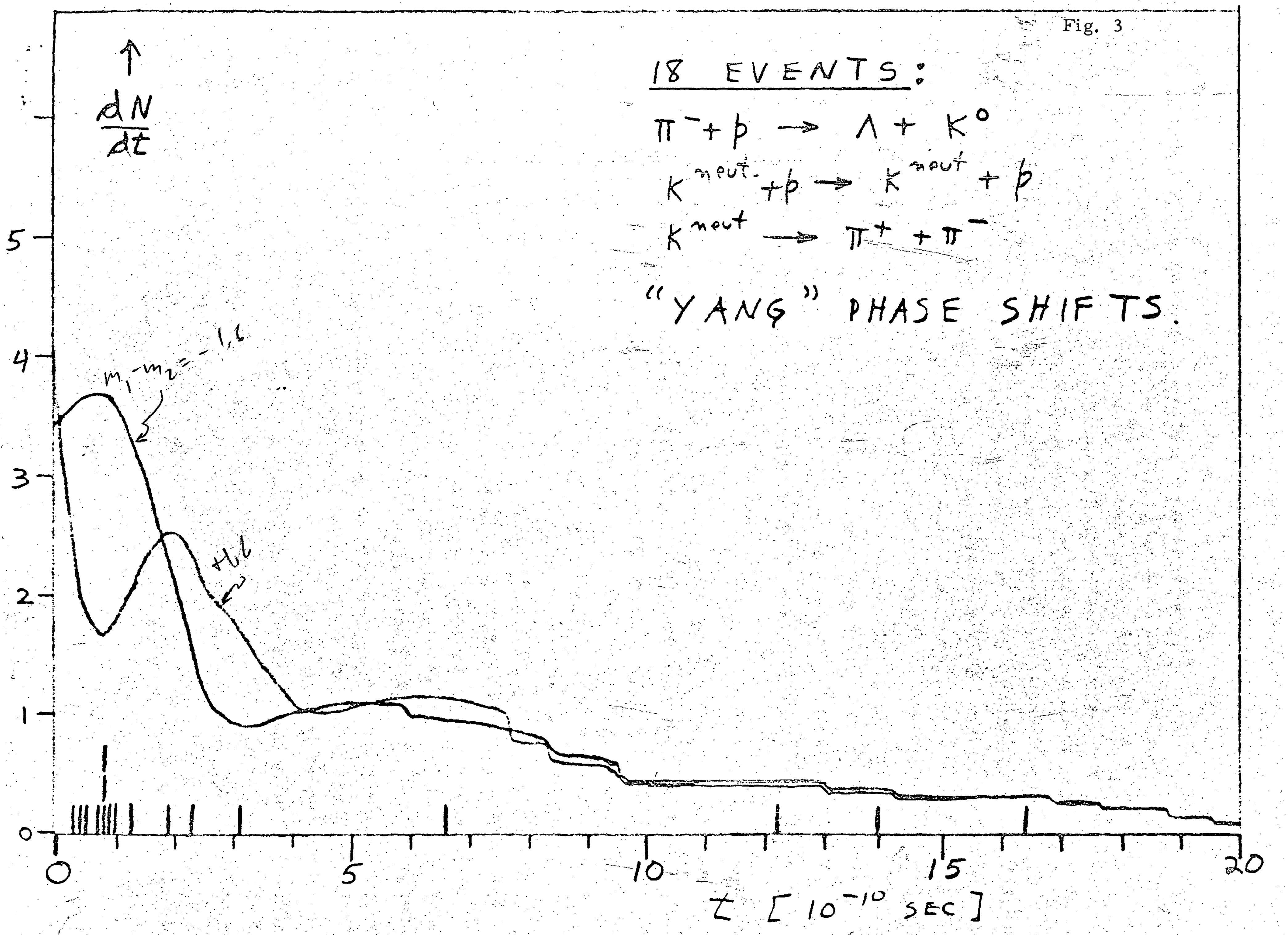

REJECT
ACCEPT
REJECT
$\bar{K}^0 p$. "1660", I = 1, RESONANCE
300
600
$P(K^0)_{LAB}$

Fig. 2

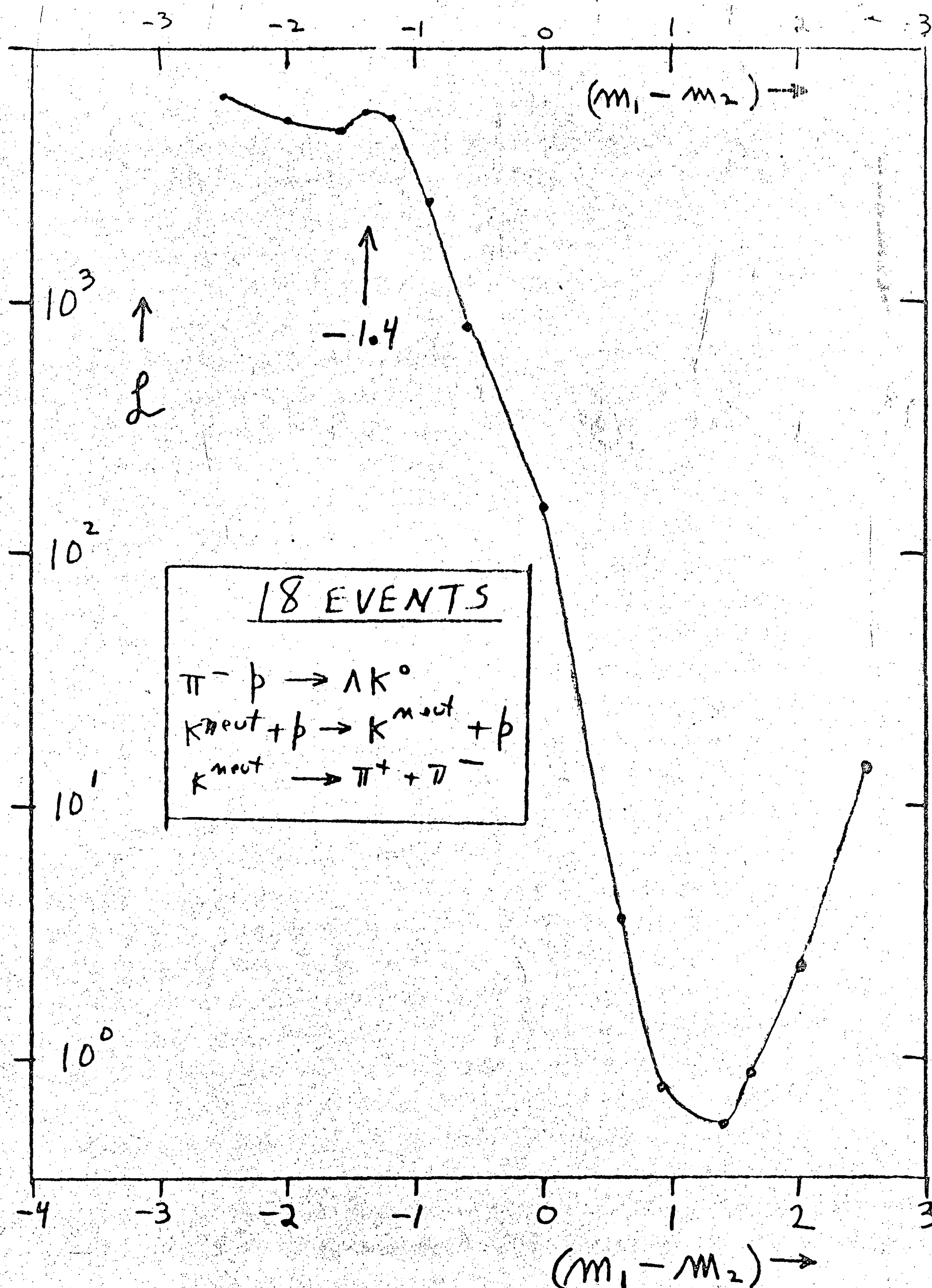


$\frac{dN}{dt}$
$m_1 - m_2 = -1.6$
$+1.6$
18 EVENTS:
$\pi^- p \rightarrow \Lambda K^0$
$K^{neutral} + p \rightarrow K^{neutral} + p$
$K^{neut} \rightarrow \pi^+ + \pi^-$
"FERMI" PHASE SHIFTS
0
1
2
3
4
5
6
0
5
10
15
20
t [10^{-10} sec]

Fig. 3



dN/dt
18 EVENTS:
π⁻ + p → Λ + K⁰
K^neut. + p → K^neut + p
K^neut → π⁺ + π⁻
"YANG" PHASE SHIFTS.
m₁-m₂ = -1,1
+1,1
t [10⁻¹⁰ SEC]
0
1
2
3
4
5
0
5
10
15
20



-3 -2 -1 0 1 2 3
(m₁ − m₂) →
10³
10²
10¹
10⁰
ℒ
−1.4
18 EVENTS
π⁻ p → ΛK°
K^neut + p → K^neut + p
K^neut → π⁺ + π⁻
-4 -3 -2 -1 0 1 2 3
(m₁ − m₂) →

Fig. 4