

Alternatively the large negative value for α could arise through an interference effect, if the signs of the Gamow-Teller and induced pseudoscalar coupling terms in the interaction Hamiltonian were the same. The last conclusion is supported by the theory of Goldberger and Treiman,¹² and by the analysis of Primakoff⁵ of the capture rate of muons in C¹².

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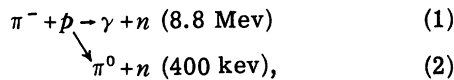
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PION MASS MEASUREMENTS USING NEUTRON TIME-OF-FLIGHT TECHNIQUES*

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Measurements of the speeds of neutrons emitted in the capture at rest of π^- mesons in hydrogen provide an excellent method for the determination of mass values for the π^- and π^0 mesons. Using energy balance of the reactions



we can deduce the mass of the π^- through Reaction (1) and the π^-, π^0 mass difference through Reaction (2). Results obtained by using time-of-flight techniques to measure the neutrons' speeds have already been reported by Gettner et al.¹ and Hillman et al.² for flight paths of 2 to 5 ft. This Letter reports preliminary results of our measurements for flight paths of 12.44 ft and 17.50 ft with similar techniques.

Figure 1 is a simplified schematic diagram of the experimental setup and electronics. The 110-Mev pions produced by an internal target of the 184-in. cyclotron were collimated into a 2-in.-high by 8-in.-wide beam; slowed down in carbon; counted by a 1-in.-thick plastic scintillator (π counter), 1.5 in. high by 8 in. long; and stopped in a liquid hydrogen target. The hydrogen flask was a horizontal cylinder 1 in. high and 12 in. in diameter. Neutrons, which travel downward, were detected in a plastic scintillator 18 in. in diameter, 1 in. thick, viewed by seven

RCA 7046 photomultipliers, through a 1-in. Lucite light pipe. Photons, from Reaction (1) and π^0 decay, which go upward, convert in a 1/4-in.-thick Pb sheet, 20 in. in diameter, 10 in. from the center of the target, and are detected by a coincidence between two plastic scintillators, each 3/8 in. thick (γ counters).

The electronics (see Fig. 1) is composed of two fast coincidences followed by a slow coincidence. One coincidence is between the π and γ counters and another is between the dynode signals of two sets of tubes of the neutron counter—the latter coincidence mode to reduce

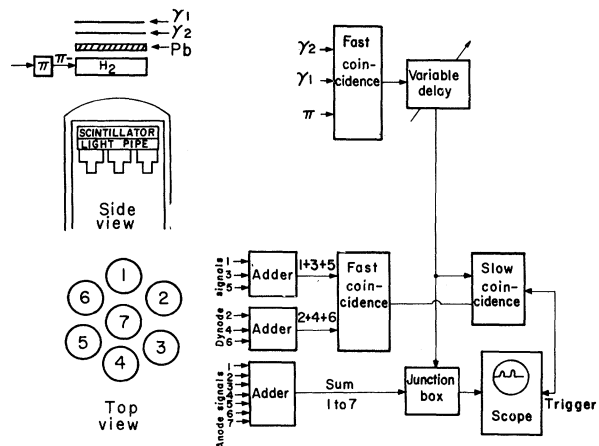


FIG. 1. Experimental arrangement.

noise accidentals. Finally a $\pi - \gamma - n$ slow coincidence is made with 200-m μ sec resolving time which triggers a 517A Tektronix scope with a 20-m μ sec/cm sweep speed. The anode signals of the neutron counter tubes are combined in a distributed adding circuit and, together with a $\pi - \gamma$ coincidence signal, are displayed on the scope sweep, of which photographs are taken. Alternate runs were made with the variable delay set for $\pi - \gamma - \gamma$ and $\pi - \gamma - n$ coincidences.

We used styrofoam delay lines for most of the inserted delay. RG-63/U delay lines were used for fine adjustment. For such long cables one must know not only the transit time of the cable but the effect of dispersion as well. A cable measuring system is used which minimizes systematic errors due to dispersion. The output of a signal generator drives a pulse shaper which puts out two pulses with the same rise time as the phototubes. The shaped pulses are fed into the vertical plates of a 5-m μ sec/cm two-beam scope, one signal coming in directly and the other via the unknown cable. A third pulse derived from the pulse shaper goes to the scope trigger. The frequency of the oscillator is adjusted so that the half-heights of the succeeding pulses coincide. When this happens the period of the oscillator is the same as the length of the cables, i.e., $L/v = 1/f$. The frequency is measured by a Hewlett-Packard 524B frequency meter. In practice we measure the length of the unknown plus a fixed cable, then remove the unknown and measure the fixed cable. The difference between the oscillator period for the two measurements is the delay through the unknown.

Dispersion effects are eliminated if the output pulse of the fixed cable is identical to a phototube pulse.

To analyze the time-of-flight data, we measured the distance between half heights of the two photographed pulses along with the amplitude of the signal from the neutron counter. We plotted the pulse-height spectrum of the background and compared it with that in the region of the neutron peak. We chose a pulse-height interval with the best signal-to-noise ratio, and measured the time distribution of the pulse in this interval for both the neutrons and the γ rays. The mean of the γ -ray distribution was used as our time reference point, and corresponds to the calculated photon flight time. The neutron flight time was taken to be: the photon flight time + the inserted delay + the difference between the mean of the neutron and γ -ray peaks. A composite plot of our measurements is shown in Fig. 2.

Table I lists the results of this experiment. The errors shown are over-all errors and are largely statistical.

The values quoted here agree favorably with recent accurate determinations by other means and by other groups. The currently recommended value of the π^- mass is $(273.27 \pm 0.11)m_e$.³ Values for the π^-, π^0 mass difference have recently been reported as $(8.8^{+0.4}_{-0.3})m_e$,⁴ $(8.9 \pm 0.14)m_e$,⁵ and $(9.01 \pm 0.08)m_e$.²

The method of computing the neutron's speed from measurement at two distances is inherently more accurate in that some systematic errors are eliminated. Scattering of the neutrons may

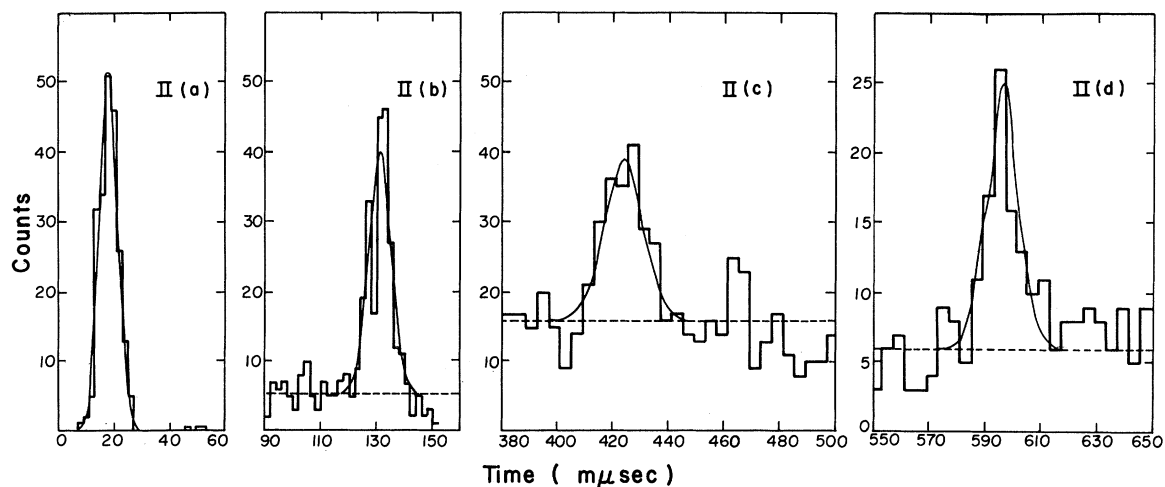


FIG. 2. Histograms of combined data. (a) γ ray at 17.50 ft; (b) 8.8-Mev neutrons at 17.50 ft; (c) 400-kev neutrons at 12.44 ft; (d) 400-kev neutrons at 17.50 ft.

Table I. Mass determinations from time of flight.

Run	Flight path (ft)	Time ($m\mu\text{sec}$)	$\pi^- - \pi^0$ mass (m_e)	π^- mass (m_e)
1	17.50 ± 0.01	130.79 ± 0.45		272.4 ± 1.1
2	12.44 ± 0.01	434.34 ± 0.79	8.984 ± 0.026	
3	17.50 ± 0.01	596.0 ± 1.1	8.998 ± 0.024	
Av(2, 3)			8.991 ± 0.020	
2 minus 3	5.055 ± 0.01	171.7 ± 1.4	9.05 ± 0.09	

shift the mean of the neutron distribution to longer times and also widen it. If the scattering is in the counter and not in the target, it will have little effect upon the value for the mass difference obtained from the difference measurement at two lengths. We have computed the scattering in the hydrogen target and found it to be negligible at these distances.

The standard deviation of the γ -ray peak is $3.5 m\mu\text{sec}$; it is 4 to 6 $m\mu\text{sec}$ for the fast neutron and 7 $m\mu\text{sec}$ for the slow neutron. The size of the neutron widths is not completely understood at present and this uncertainty does not allow us to infer a meaningful limit for the π^0 lifetime.

The background in our neutron counter is currently limiting us in our ability to obtain more accurate measurements with longer flight paths. It appears to be due to three causes: radiation from the target, which decreases with solid angle and beam level; tube noise, which is con-

stant but relatively small; and an effect that is of about constant value with depth. We are in the process of reducing the latter to allow us to increase the flight path by an appreciable factor.

We gratefully acknowledge the efforts of the many individuals who have assisted us in this experiment.

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STRANGENESS 2 MESON

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In a previous communication¹ evidence was presented for a new strange particle. The interpretation of our event assigned to this particle a strangeness -2, a negative single charge, and a mass in the neighborhood of 700 Mev. According to the conventional scheme, a meson of strangeness 2 should occur as an isotopic singlet. The particle would have $Q = +1$ and $S = +2$; the antiparticle would have $Q = -1$ and $S = -2$. We shall call them D^+ and D^- , respectively. The event discovered² at Dubna, which motivated

our search, may constitute evidence for the D^+ , while ours suggests the existence of D^- .

We wish to report some interpretations of certain other anomalous events which seem to lend support to the D -particle hypothesis. First, there are the several anomalous decays of "K" mesons both at rest and in flight. An event has been reported³ by a Columbia group, who saw a presumed K^+ decaying at rest into a 60-Mev π^+ . They interpreted this as being a decay mode $K^+ \rightarrow \pi^+ + \pi^0 + \gamma$, and showed that 60 Mev is near the