MEASUREMENT OF THE π^0 MASS, AND SEARCH FOR A $\pi_0{}^0$*

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Although the mass of the π^0 meson has been reported[1] measured with an accuracy of about $0.3m_e$ (electron masses), the experiments on which this result is based were analyzed on the assumption that only a single π^0 exists, and these experiments could in fact have failed to detect the existence of two different π^0 mesons if two were produced in the reaction studied,

$$\pi^- + p \to n + \pi^0 \searrow 2\gamma. \tag{1}$$

Since the "existence" of a second neutral meson $\pi_0{}^0$, with isotopic spin $T=0$, may be expected in addition to the ordinary π^0 meson ($T=1$), and since the possibility that the masses of $\pi_0{}^0$ and π^0 might be relatively close does not appear excluded by present knowledge,[2] it appears worthwhile to carry out a more direct measurement to determine the mass or masses. We report here the results of a preliminary experiment for this purpose. This work gives the first direct demonstration, to our knowledge, of a neutron group corresponding to a well-defined π^0 mass. Accompanying this result is a direct measurement of a lower limit on the lifetime of this meson.

π^- mesons were stopped in a thin (2 cm) liquid hydrogen target, and the neutrons produced were measured by time of flight, with an arrangement indicated in Fig. 1. A "zero-time" signal from the γ-detector was demanded for each neutron-detector signal recorded; the γ-detector signal was further required to be in close time coincidence (within about 10 nanoseconds $= 10 \times 10^{-9}$ sec), with an incoming particle in the π^- beam.

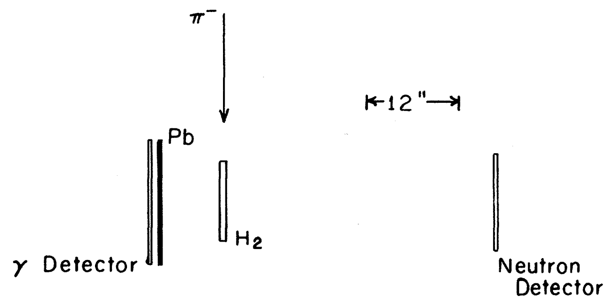

FIG. 1. Experimental arrangements.

Peaks in the time-of-flight distribution were observed corresponding to the two types of reaction known to occur for π^- mesons stopped in hydrogen, namely reaction (1) above and

$$\pi^- + p \to n + \gamma. \tag{2}$$

Another group was observed near zero flight time. Such a group is expected for $\pi^0 \to 2\gamma$ events in which the "neutron" detector responds to one of the γ rays. The "zero-flight-time" group also includes some background events, coming from neutron stars produced by π^- capture in the hydrogen target structure.

The time-of-flight distribution for a neutron detector distance of 3 feet is shown in Fig. 2. The zero of the abscissa scale is determined by electronic time delays in various legs of the recording system. The group at $\Delta t = 59$ is the "zero-flight-time" group, and that at $\Delta t = 78$ is the 8.8-Mev group from reaction (2) above. The intrinsic time resolution of the system, measured separately, was about 2 nanoseconds (full width at half-maximum). The position of γ-γ events (and consequently the position of true zero time of flight) in the group at $\Delta t = 59$ can be narrowed down by making use of pulse-height information from the neutron detector. From the data of Fig. 2, the energy of the 8.8-Mev group is found to agree with the value calculated from the known masses of π^-, neutron, and proton, to an accuracy corresponding to about 1 nanosecond of flight time.

A group of neutrons of approximately 0.4 Mev energy is expected from reaction (1). As calculated from the previously reported calculated best value for the mass difference[1]

$$m_{\pi^-} - m_{\pi^0} = (9.0 \pm 0.3) m_e, \tag{3}$$

this group should occur at approximately the position of the arrow in Fig. 2. No group near this position showed clearly in these data. It

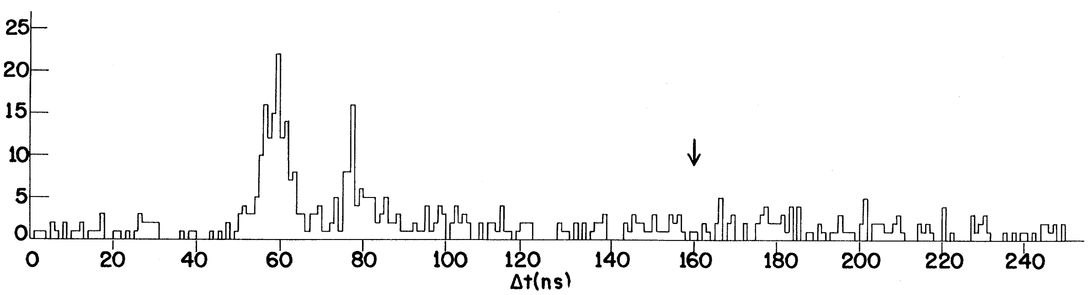

FIG. 2. Time-of-flight distribution for a neutron detector flight path of 3 feet. Number of events per 1-nanosecond (ns) interval is plotted against time difference between γ-detector and neutron-detector signals. Neutron-detector signals of all sizes are included.

could be expected that the effective background intensity contributing in Fig. 2 could be reduced by accepting only those neutron-detector pulses meeting an appropriate pulse-height requirement, but even so no clear group could be identified in the data.

Further data were taken with a shorter flight path, two feet, to reduce background. The result of this run, in the vicinity of the expected group, and with an appropriate choice as to maximum acceptable pulse height for the neutron-detector signal, are shown in Fig. 3(a). Here a group shows clearly, at about 32 nanoseconds/foot, near the expected position.

The 2-foot data of Fig. 3(a) and the 3-foot data of Fig. 2, combined (using the same value for the maximum acceptable pulse height), give the results in Fig. 3(b). The principal peak corresponds to a mass difference

$$m_{\pi^-} - m_{\pi^0} = (9.6 \pm 0.5) m_e. \tag{4}$$

The uncertainty given is due principally to (estimated) uncertainty in the exact position of true zero on the time-of-flight scale.

The result (4) is consistent with the previous best value (3). The existence of a π^0 meson with approximately the mass previously assigned to it is thus directly verified.

Although the existence of a second neutral π meson, the π_0^0, with mass near that of the π^0, cannot be strongly expected on the basis of previous knowledge, the data of Fig. 3 do not exclude the existence of such a π_0^0 with high confidence. The bump in the vicinity of 40 nanoseconds/foot, although of obviously poor statistical significance,

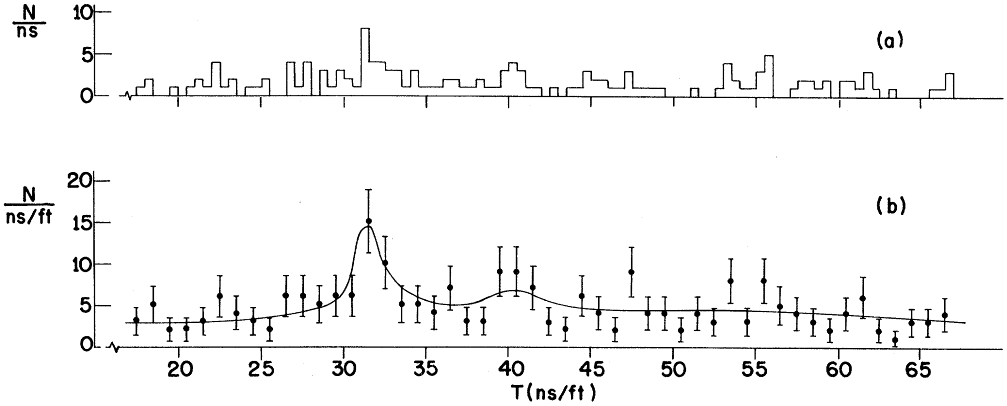

FIG. 3. (a) Data for neutron detector flight path of 2 feet. The abscissas give time difference (per foot) with respect to γ-γ signals. A neutron-detector-signal maximum pulse-height limit was imposed corresponding to neutrons of about 0.5-Mev energy. (b) Distribution consisting of (a) added to those events from the data of Fig. 2 satisfying the pulse-height criterion used in (a).

nevertheless consists principally of a group of events having neutron-detector pulse height appropriate to a neutron group of this time-of-flight. (The corresponding mass of the "second π^0" would be about 1.3 Mev heavier than that corresponding to the group at 32 nanoseconds/foot.) More refined measurements, which we hope to carry out, will be necessary to permit a more positive statement concerning a possible second group.

With more refined measurements it should also be possible to obtain a check of the Panofsky ratio.

Finally, the present results give directly a lower limit on the lifetime of the π^0 meson. This value is obtained through the uncertainty principle $\Gamma\tau \approx \hbar$, where Γ is the energy width of the π^0 and τ is the mean life. The degree of sharpness of the π^0 mass shown by the data gives

$$\tau > 3\times10^{-21}\text{ sec.} \tag{5}$$

This value is far below the value expected theoretically.[3] It may be of some interest, however, since it is the first direct measurement giving a lower limit on the lifetime of the π^0 meson. Other experimental information on the lifetime is discussed, with references, in the report of Harris et al.,[4] which also gives an upper limit to the lifetime. It is true, however, that other measurements exist which, although less direct than the present one, have been analyzed to give a lower limit of 10^{-19} sec for the mean life.[5,6] It may be remarked that extending the present approach to the limit that at this time appears practical could be expected to cover the lifetime range up to 10^{-19}–10^{-18} sec.

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[1] Cohen, Crowe, and Dumond, Fundamental Constants of Physics (Interscience Publishers, New York, 1957), p. 47.

[2] W. Selove (to be published).

[3] See M. L. Goldberger and S. B. Treiman, Nuovo cimento 9, 461 (1958).

[4] Harris, Orear, and Taylor, Phys. Rev. 106, 327 (1957).

[5] L. Osborne (private communication).

[6] F. E. Low (private communication).

POLARIZATION OF RECOIL PROTONS FROM THE PHOTOPRODUCTION OF π^0 MESONS FROM HYDROGEN*

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Sakurai[1] has pointed out that Peierls'[2] assignment of $D_{3/2}$ for the second resonance in photopion production predicts a strong polarization of the recoil protons from the reaction $\gamma + p \rightarrow p + \pi^0$ in the region of the second resonance. In particular, it can be shown that if an appreciable polarization is found at a recoil proton angle of 90° in the center-of-mass system at photon energies in the region of about 600 Mev, the parity of the 700-Mev resonances must be opposite to the parity of the 300-Mev resonance.

The polarization of the proton recoils has been measured at photon energies of 550 Mev and 700 Mev at a center-of-mass angle of 90° by allowing the protons to be incident upon a carbon scatterer and observing the left-right asymmetry in the scattering. The apparatus is shown in Fig. 1. The photon beam from the Cornell electron synchrotron is incident upon a vacuum liquid-hydro-

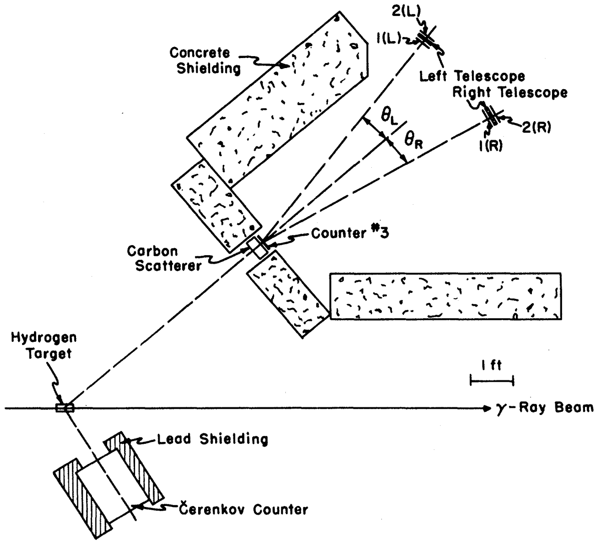

FIG. 1. Experimental apparatus for measuring the recoil proton polarization in the reaction $\gamma + p \rightarrow p + \pi^0$.