[*] Supported in part by the U. S. Atomic Energy Commission.

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[1] Eisler, Plano, Samios, Schwartz, and Steinberger, Nuovo cimento 5, 1700 (1957).

[2] 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN Scientific Information Service, Geneva, 1958), p. 273, Tables VI and VII.

[3] Crawford, Cresti, Douglass, Good, Kalbfleisch, Stevenson, and Ticho, Phys. Rev. Letters 2, 266 (1959).

[4] D. A. Glaser, Handbuch der Physik, edited by S. Flügge (Springer-Verlag, Berlin, 1958), Vol. 45, p. 314.

[5] If one assumes the approximate validity of the $\Delta I = 1/2$ selection rule, the actual value of B_K can be related to pion-pion scattering phase shifts in the $I=2$ and $I=0$ isotopic spin states. See M. Gell-Mann, Nuovo cimento 5, 758 (1957) and R. H. Dalitz, Proc. Phys. Soc. (London) A69, 527 (1956).

[6] Phase space corrections arising from the mass differences between neutrons and protons, and between $\pi^{\pm}$ and π^0 are much smaller than our statistical errors and have, therefore, been neglected.

[7] This requirement is imposed by restricting ourselves to those interactions from which all charged prongs stop without decaying inside the chamber.

[8] When we speak of a directly produced Λ, we mean that the hyperon which leaves the xenon nucleus in which the production takes place is a Λ. We make no distinction between a Λ which is actually the product of the initial pion-nucleon collision, and one which arises from the secondary interaction, in the same nucleus, of an initially produced Σ.

SEARCH FOR $\pi_{10}{}^0 \rightarrow 3\gamma$*

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The possible existence of a neutral meson of isotopic spin zero has been discussed in many connections.[1] The present note reports an experiment[2] to look for such a meson, using a method which covered only a small part of the possible mass spectrum, and which could detect the 3γ decay of a neutral meson of mechanical spin one, the $\pi_{10}{}^0$, but which could not detect the 2γ decay of the ordinary π^0. A small net effect of the form we sought was observed. However, because of the complexity of the expected background processes at such low cross sections, our experiment is not at all conclusive.

The experimental arrangement is shown in Fig. 1. The 160-Mev unpolarized external proton beam of the Harvard cyclotron falls on a 0.6-g/cm^2 target of ordinary lithium. A γ ray coming from the target is detected by one of three high-Z energy-sensitive Čerenkov counters. The Čerenkov liquid is $C_2H_2Br_4$, with a radiation length of 4.5 cm and an index of refraction such that protons of less than 210 Mev kinetic energy cannot give Čerenkov light directly. A counter consists of a $C_2H_2Br_4$ cylinder 13 cm long by 15 cm in diameter, viewed at each end by an RCA No. 7046 14-stage photomultiplier (shown on C_1 only) and placed with the counter axis normal to the direction from the target.

The threshold bombarding energy for production of ordinary π^0 mesons in the reaction $p + \mathrm{Li}^7 \rightarrow \mathrm{Be}^8 + \pi^0$ is 135 Mev. The maximum kinetic energy with which an ordinary π^0 can emerge at 120° in the laboratory is 21 Mev. The line from the

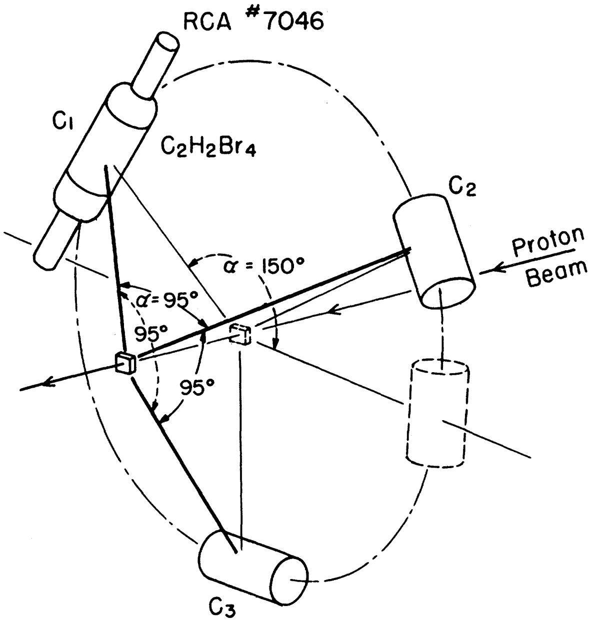

FIG. 1. Counter arrangement for twofold coincidence detection of γ rays from $\pi_{10}{}^0 \rightarrow 3\gamma$.

target to each counter makes an angle of 120° with the beam direction. With the counters set at the angles shown ($\alpha = 95^\circ$ subtended by the center line of each pair of counters at the target), twofold coincidence detection of the two γ rays from the $\pi^0 \to 2\gamma$ decay by any part of the exposed area of the counters is forbidden kinematically.

On the other hand, two of the three γ rays from $\pi_{10}{}^0 \to 3\gamma$ can make a twofold coincidence in any of the three pairs of counters, provided such a $\pi_{10}{}^0$ can be produced at all. Note that the solid angle subtended by each counter (10^{-3} sterad) is such that no appreciable number of triple coincidences from $\pi_{10}{}^0 \to 3\gamma$ could be expected in this experiment. The purpose of having three counters instead of two is only to give a badly needed factor of three in intensity.

In addition to kinematic selectivity, the counters are biased so as to give appreciable energy selectivity. Their pulse-height responses were studied as a function of the energy of monoenergetic electrons produced by the MIT synchrotron. Their differential cosmic-ray pulse-height responses were used to monitor the biases during the run.

In order to run at high beam intensities, considerable effort was made to suppress the large neutron background. The mechanism by which neutrons could give counts with an efficiency of about 10^{-4} in the $C_2H_2Br_4$, and also in the lead glass counters used in preliminary runs, was not studied. The part of the background not associated with the target was reduced by shielding the detectors by 32 in. of lead and by replacing the air in the beam path with hydrogen. Crude absorption curves indicate that the residual target-associated singles at typical biases were about half neutrons and half γ rays. We estimate from the yields given below that π^0 decay accounts for most of the detected γ rays coming from the target.

To suppress accidental counts, fast coincidences (3×10^{-9} sec) between all four photomultipliers of each of the three possible pairs of counters were made in Berkeley circuits[3] set at low bias. To give energy discrimination, the pulses from each pair of photomultipliers on a given counter were then added, gated by the fast coincidence, and put through a Moody discriminator. The final coincidence outputs were formed by a redundant set of slower (20×10^{-9} sec) coincidence circuits. Delayed accidental coincidences between events from successive cyclotron pulses 42×10^{-9} sec apart were similarly processed and separately recorded in a parallel set of electronics. In order to remove systematic differences between the two sets, their roles were interchanged periodically between two modes of operation, called "X" and "Y."

First the excitation curve for ordinary $\pi^0 \to 2\gamma$ was measured with only one pair of counters; they were both at 90° to the beam axis and subtended an angle $\alpha = 150^\circ$ at the target (see Fig. 1). The beam energy was varied by use of CH_2 absorbers, relying on the calculated ionization loss. The yield of π^0's from lithium as a function of proton energy is given in Fig. 2. The yields at $\alpha = 150^\circ$ and a fixed energy $E_p = 160$ Mev are compared for a few different elements in Table I.

Then with the counters moved to the symmetric position shown in Fig. 1, with $\alpha = 95^\circ$ for each of

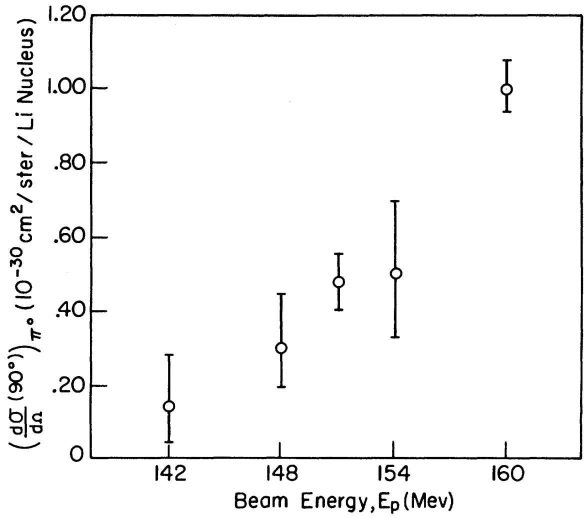

FIG. 2. Cross section for $p + Li^7 \to Be^8 + \pi^0$.

Table I. $[d\sigma(90^\circ)/d\Omega]_{\pi^0}$ for several elements, in units of 10^{-30} cm² sterad^{-1} nucleus^{-1}.

Element	Li	C	Al	Cu	Pb
$[d\sigma(90^\circ)/d\Omega]_{\pi^0}$	1.0 ± 0.1	0.3 ± 0.1	0.4 ± 0.1	0.3 ± 0.1	0.2 ± 0.1

Table II. Summary of coincidence data at $\alpha = 95°$.

Delay mode	Monitor counts[a]	Prompt coinc.	Delayed coinc.	Net[b]
	Beam energy = 160 Mev			
X	3900	55	32	23
Y	3250	45	22	23
Total	7150	100	54	46
	Beam energy = 133 Mev			
X	3900	30	37	-7
Y	2600	30	16	+14
Total	6500	60	53	7

[a] One monitor count = 4×10^9 protons.

[b] For comparison, the equivalent net ordinary π^0 coincidence counts ($\alpha = 150°$) at 160 Mev would be 2145 for 7150 monitor counts.

the three pairs of counters, the data given in Table II were obtained. The net rate observed at 160 Mev was $(2.0 \pm 0.6)\,\%$ of that from three pairs of counters counting ordinary π^0's in the $\alpha = 150°$ position.

Of the many types of background considered, only the following processes are expected to contribute appreciably to this net rate: (1) cosmic-ray coincidences, measured to give $(20 \pm 2)\,\%$ of the above net rate, (2) coincidences between one of the electrons and the gamma in the Dalitz pair decays, $\pi^0 \rightarrow e^+ + e^- + \gamma$, estimated to give $(10 \pm 3)\,\%$, and (3) coincidences between one of the γ rays from the π^0 and the nuclear γ ray in the reaction

$$p + \mathrm{Li}^7 \rightarrow \mathrm{Be}^{8*} + \pi^0 \rightarrow \mathrm{Be}^8 + \gamma(17\ \mathrm{Mev}) + 2\gamma,$$

estimated to give $(8 \pm 4)\,\%$.

The corrected net rate at $E_p = 160$ Mev, after subtracting these three backgrounds, is $(1.2 \pm 0.6)\,\%$ of the $\alpha = 150°$ ordinary π^0 equivalent counting rate. [At $E_p = 133$ Mev the net rate is $(-0.1 \pm 0.5)\,\%$.]

This rate would correspond to a differential cross section for production of the $\pi_{10}{}^0$ of $(d\sigma/d\Omega)_{\pi_{10}{}^0} = (1.6 \pm 0.8) \times 10^{-32}$ cm^2 sterad^{-1} (lithium nucleus)$^{-1}$, or $(2 \pm 1) \times 10^{-33}$ cm^2 sterad^{-1} nucleon^{-1}.

Akimov *et al.*[1] have in the meantime set an upper limit a factor of two lower than this for production of *any* neutral meson in another reaction $d + d \rightarrow \pi^0 + \mathrm{He}^4$, with considerably more energy available for the π^0 in the c.m. system.

In order to tell whether the net effect we observe is statistically and instrumentally well established, and in order to study the background processes in detail, we would have to work at a higher counting rate, requiring in turn considerable reduction of the target-associated background processes (2) and (3) above. This is very difficult to accomplish using a lithium target, but might be done by bombarding a hydrogen target with 350-Mev protons. Normal p-wave π^0 production is known to be suppressed by the parity and angular momentum selection rules, but there is no reason to believe that $\pi_{10}{}^0$ production would be suppressed. A collimated beam of 10^8 protons per seconds should suffice for a 2γ-detection counter experiment like this one. To provide sufficient solid angle for the conclusive detection of all three γ rays, the hydrogen target would need to be surrounded by a high-Z bubble chamber or electronic hodoscope.

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