nucleon-nucleus case, it is possible to predict that the diffraction dissociation of the target nucleon into a nucleon and a pion must take place, at our energies, only when ~1 Gev is absorbed and that it must be present, of course, only when the elastic diffraction scattering is present. Only further experiments will enable us to confirm, or not, this suggestive interpretation.

Finally, we want to point out that the existence of the quasi-elastic collisions (the quasi-elastic continuum) for ultrarelativistic protons can have interesting applications.

One concerns radiochemistry. When the quasi-elastic event takes place for the target nucleon embedded in a nucleus it is easily seen that the final momentum of the target nucleon, in the lab system, can be so small as to leave the nucleon inside its original nucleus. The exchange of a pion can then give rise to a nuclear reaction of the type $X_Z{}^A(p,p\pi^{\mp})Y_{Z\pm1}{}^A$. The cross sections evaluated for this phenomenon seem to be of the right order of magnitude for explaining several reactions of this kind, as well as others of similar character, produced by ultrarelativistic protons.[9]

A second remark concerns the possibility of using quasi-elastic events for building a separator of ultrarelativistic antiprotons. Whereas it is expected that the quasi-elastic cross section of antiprotons is equal to that of the protons, the mesons should have quasi-elastic cross sections substantially smaller, being unable to exchange a single pion with a nucleon. A monochromatic secondary beam of ultrarelativistic negative particles containing antiprotons, pions, K mesons, and muons should then, when scattered by a target, give a tertiary beam of quasi-elastic particles enriched in antiprotons according to the ratio of the cross sections. Guesses about intensities and cross sections seem to indicate that such a separator could be of value for bubble chambers at momenta where most of the separators suggested so far will certainly fail. A separator of this kind would also be relatively cheap.

These measurements would have been impossible without the warm collaboration of the proton synchrotron staff. We want to thank in particular Mr. J. Gervaise, who acted as liaison man between our group and the Machine Group. We also thank Mr. C. A. Stahlbrandt for his skillful help with the electronics.

---

[1] The term ultrarelativistic is used here for a nucleon with Lorentz factor γ = total energy/rest mass >> 1.

[2] F. Salzman and C. Salzman, Phys. Rev. Letters 5, 377 (1960).

[3] S. D. Drell, Phys. Rev. Letters 5, 342 (1960).

[4] K. H. Reich, CERN Internal Report MG-VA 60-37 (unpublished).

[5] The angle of 60 mrad was chosen because, for the time being, it is the smallest angle at which the particles from the target can leave the doughnut through a Mylar window.

[6] G. von Dardel group (private communication).

[7] J. v. Behr and R. Hagedorn, CERN Internal Report 60-20 (unpublished).

[8] M. L. Good and W. D. Walker, Phys. Rev. 120, 1857 (1960) [see also E. L. Feinberg and I. I. Pomeranchuk, Suppl. Nuovo cimento 3, 652 (1956)].

[9] T. I. O. Ericson, F. Selleri, and R. Van de Walle (private communication).

SEARCH FOR THE ω^0 IN PHOTOPRODUCTION

K. Berkelman,* G. Cortellessa, and A. Reale
Laboratori di Fisica, Istituto Superiore di Sanità, Roma, Italy

(Received February 8, 1961)

A recent investigation by Abashian, Booth, and Crowe[1] of the He^3 recoil momentum spectrum in the reaction

$$p+d\rightarrow He^3+\ldots, \tag{1}$$

has revealed, in addition to the peak associated with π^0 production and the continuum associated with double-pion production,

$$p+d\rightarrow He^3+\pi^0, \tag{2}$$

$$p+d\rightarrow He^3+\pi^++\pi^-, \tag{3}$$

$$p+d\rightarrow He^3+\pi^0+\pi^0, \tag{3'}$$

an anomalous peak which has been interpreted as being associated with a resonant state of two pions or a particle of mass 310 ± 10 Mev. In the following we shall refer to this particle or resonance (the distinction is perhaps only a matter of lifetime) as if it were a particle ω^0:

$$p+d\rightarrow He^3+\omega^0. \tag{4}$$

In the present experiment we have attempted to produce the ω^0 by the reaction

$$\gamma + p \rightarrow p + \omega^0, \tag{5}$$

using the bremsstrahlung beam of the Frascati 1-Bev electron synchrotron. If the ω^0 is actually a two-pion resonant state, one would expect a rapid breakup into two pions:

$$\omega^0 \rightarrow \pi^+ + \pi^-, \tag{6}$$

$$\omega^0 \rightarrow \pi^0 + \pi^0. \tag{6$'$}$$

If the ω^0 is instead a new particle, a fast decay into two pions still seems quite likely. An alternate decay mode,

$$\omega^0 \rightarrow \pi^0 + \gamma, \tag{7}$$

if it existed, would probably have been detected by Gomez et al.[2] in their search for the "B^0 meson." An attempt at detecting the ω^0 was then made on the basis of its expected mass and the charged-pion decay mode.

The experimental arrangement is shown in Fig. 1 and is quite similar to that used by Cortellessa and Reale in studying the photoproduction of π^0 mesons.[3] The collimated bremsstrahlung photon beam passed through a liquid hydrogen target and was monitored by the quantameter.[4] The recoil photons were detected by a range telescope (four scintillators in coincidence, one in anticoincidence) with a 20-Mev definition in gamma-ray energy. On the other side the π^+ and π^- from the decay of the ω^0 were detected by two scintillation counters in coincidence placed behind 15 radiation lengths of lead. The lead made the pion telescope less sensitive to neutral pions and gamma rays as well as reducing the singles rates, which would have been quite intolerable since the telescope had a rather large area and was placed at a small angle to the beam. The kinematics conditions fixed by the proton energy and angle were chosen to enable the ω^0 to be produced with enough laboratory energy so that its decay pions would come out in a small cone and could be caught with good efficiency by the pion telescope.

There is no experimentally observable difference between the production of an ω^0 of mass 310 Mev, decaying rapidly into two pions, and the direct production of two pions with a total energy of 310 Mev in their own center-of-mass system:

$$\gamma + p \rightarrow p + \pi^+ + \pi^-. \tag{8}$$

That is, a pair of pions produced with a Q (total kinetic energy in their c.m. system) of 30 Mev will be counted in the pion telescope with exactly the same efficiency as if it had come from the decay of an ω^0. The ω^0 should show up only as a peak in the double-pion Q spectrum at the energy

$$Q = M_{\omega^0} - 2m_\pi = 30 \text{ Mev.}$$

By fixing the proton recoil energy and angle and the incident gamma-ray energy, one determines the Q of the pion-pion system. Then, varying the incident gamma-ray energy, one traces out the Q spectrum for the double-pion production, provided that the production cross section does not vary significantly over the range of incident photon energy scanned. Because of the fact that the gamma-ray beam is not monoenergetic but instead has the well-known bremsstrahlung spectrum, one obtains after appropriate normalization the integral Q spectrum for double-pion

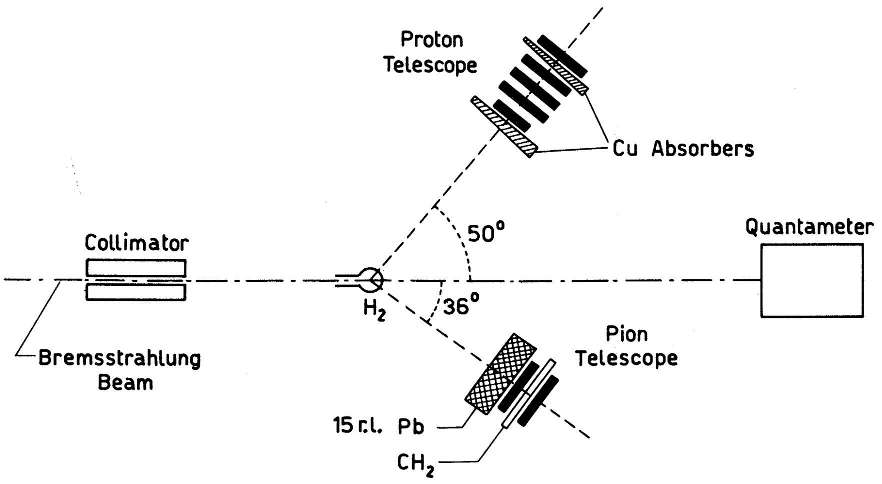

FIG. 1. The experimental setup (not drawn to scale).

production. This integral spectrum should be a smoothly increasing function of Q (reaction 8) with a superimposed step at $Q = M_{\omega^0} - 2m_\pi$ due to ω^0 production and decay (reactions 5 and 6).

In the present experiment the threshold for producing the ω^0 with a recoil proton at an energy of 160 Mev at 50° in the lab system was 950 Mev. The beam energy was varied from 880 Mev (below the double-pion threshold for these conditions) to 1020 Mev, thus scanning Q from zero to 65 Mev, or M_{ω^0} from 280 to 345 Mev. Starting from a background rate of about 0.05 count/10^{10} equivalent quanta, probably due to neutral pion decays, the counting rate (Fig. 2) shows a fairly smooth rise with energy, presumably due to pion-pair production, with no statistically significant ω^0 threshold step. The errors shown represent only counting statistics. Any systematic errors are not expected to vary significantly with energy or affect the interpretation of the data. Also plotted in Fig. 2 is the expected counting rate calculated under the following assumptions: (1) The pion-pion Q spectrum is proportional to phase space, (2) the laboratory differential cross section $d\sigma/d\Omega_p$ for double-pion production with proton recoil at the angle and energy selected in the experiment is about 5 μb/sr,[5] and (3) there is no ω^0. The dashed curve shows the ω^0 contribution for an assumed 0.1-μb/sr production cross section. From Fig. 2 one can set an upper limit for the center-of-mass differential cross section for reaction 5:

$$d\sigma/d\Omega < 0.05\ \mu\text{b/sr},$$

at $E_\gamma \approx 950$ Mev and $\theta_{\text{c.m.}} = 63°$. This limit holds for any ω^0 mass between 280 Mev and 330 Mev. It should be noted that the ω^0 peak observed by Abashian et al. is about 1/5 as large as their π^0 peak and is easily observed superimposed on the double-pion spectrum. The ω^0 photoproduction yield in the present experiment is less than 1/30 of the π^0 yield at the same energy and angle and is certainly small compared with the direct double-pion yield.

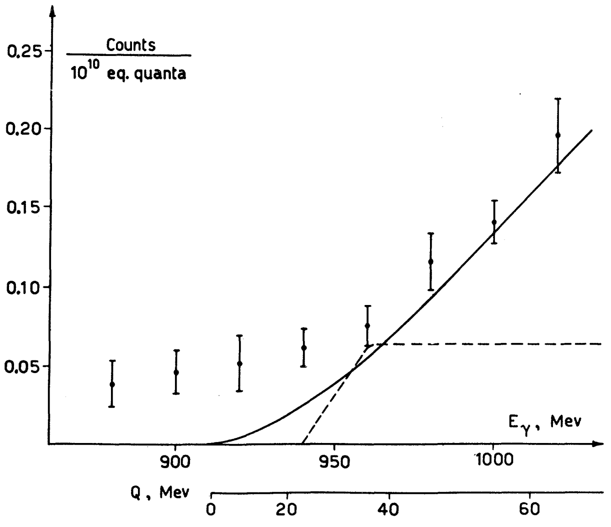

FIG. 2. The counting rate, corrected for pion telescope efficiency, as a function of the bremsstrahlung end-point energy. The corresponding Q of the $\pi\pi$ system (reaction 8) is shown by the bottom scale. The solid curve shows the expected yield from reaction 8; the dashed curve shows the yield from reaction 5 assuming $d\sigma/d\Omega = 0.1\ \mu$b/sr.

It seems reasonable that if the ω^0 were a resonant state of two pions causing an anomalous final-state interaction in double-pion production, it should show up about as strongly relative to normal double-pion production in the $\gamma + p$ process as it did in the $p + d$ process. This is clearly not the case. There are at least two other alternatives. (1) The ω^0 could be a particle which somehow has an anomalously small photoproduction cross section. (2) The ω^0 could be a long-lived particle or give decay products not detectable in the pion telescope. Even in the latter case one can set an upper limit on the photoproduction cross section using the proton recoil data alone, in the manner of Bernardini et al.[6] The present experiment gives the same upper limit as reference 6:

$$d\sigma/d\Omega < 0.3\ \mu\text{b/sr}.$$

---

*On leave from Cornell University, visiting scientist at the Istituto Superiore di Sanità with a grant from the National Science Foundation.

[1] A. Abashian, N. E. Booth, and K. M. Crowe, Phys. Rev. Letters 5, 258 (1960).

[2] R. Gomez, H. Burkhardt, M. Daybell, H. Ruderman, M. Sands, and R. Talman, Phys. Rev. Letters 5, 170 (1960).

[3] G. Cortellessa and A. Reale, Nuovo cimento 18, 1265 (1960).

[4] R. R. Wilson, Nuclear Instr. 1, 101 (1957).

[5] B. M. Chasan, G. Cocconi, V. T. Cocconi, R. M. Schectman, and D. H. White, Phys. Rev. 119, 811 (1960).

[6] C. Bernardini, R. Querzoli, G. Salvini, A. Silverman, and G. Stoppini, Nuovo cimento 14, 268 (1959).