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Reaction $\pi^- p\to\gamma\gamma n$ at 3.65 GeV/c*

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New results are presented for the reactions $\pi^- p\to m^0 n$ at 3.65 GeV/c, where m^0 represents η or η' decaying to $\gamma\gamma$. We have seen 31 η' events over a small background, leading to a branching ratio $(\eta'\to\gamma\gamma)/(\eta'\to\text{all})=0.020^{+0.008}_{-0.006}$. Over 2000 η events were observed, and the differential cross section exhibits a dip at $-t=1.5$ (GeV/c)^2.

An experiment has been performed to study the electromagnetic decays of neutral mesons in the reaction $\pi^- p\to m^0 n$ at 3.65 GeV/c. The experiment was carried out at Argonne National Laboratory using optical spark chambers. In this Letter we report on those mesons which decay to two photons.

The experimental setup is shown in Fig. 1. The pion beam was defined by two scintillation counters B_1 and B_2 and an anticoincidence counter V_3 which contained a hole to permit passage of the beam. The 6-in.-long liquid-hydrogen target was surrounded by anticoincidence counters, those at the sides of the target being in the form of lead-scintillator sandwiches. This arrangement selected events only when photons were emitted at

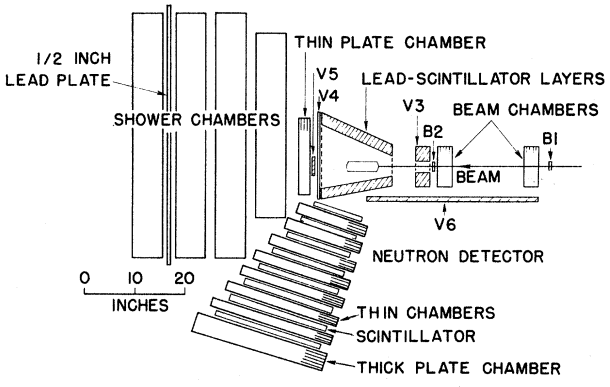

FIG. 1. Experimental setup. B_1, B_2 are beam counters, $V_{3,4,5,6}$ are anticoincidence counters.

angles less than approximately 40° from the incident beam. These photons were detected in steel-plate spark chambers having a total thickness of 9 radiation lengths.

Neutrons emitted at angles greater than 45° were detected by coincident signals from at least two adjacent scintillators in an arrangement of seven alternate layers of 1-in.-thick plastic scintillators and thin-plate spark chambers. This angular region corresponded to that of neutrons emitted from reactions producing mesons with masses up to 1100 MeV/c^2 at squared four-momentum transfer $-t$ up to 2 (GeV/c)^2. The detector intercepted neutrons in an azimuthal angular range of approximately 60°.

The average trigger rate was 6×10^{-6} per incident pion. Approximately 10^5 events were photographed.

All events with two photon showers separated by at least 10° in the shower chambers, and with an observable track in the neutron detector, have been measured. The opening angle criterion provided a strong discrimination against the very copious π^-p charge-exchange events and removed no events where the effective mass of the photon pair exceeded 400 MeV/c^2. The final data sample includes approximately 3000 events.

A knowledge of the incident beam direction and momentum and of the directions of the final-state photons and neutron provided a one-constraint kinematical fit to the data. The resultant effective-mass spectrum for the photon pairs is shown in Fig. 2.

The effective-mass spectrum shows a clear η signal and, in addition, a sharp peak centered at

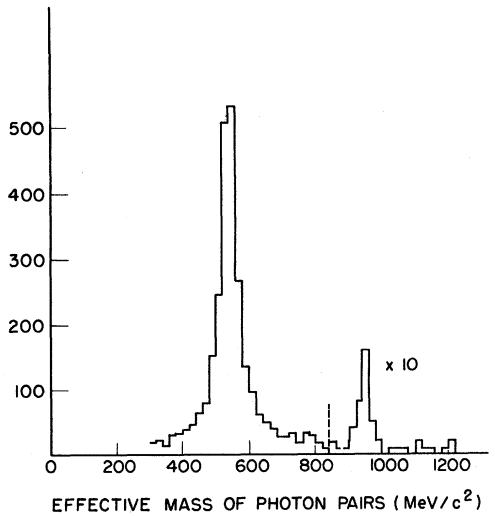

FIG. 2. Effective-mass spectrum for photon pairs.

950 MeV/c^2. We associate this peak with the decay $\eta' \to 2\gamma$. The events in the mass region above 850 MeV/c^2 have been carefully rescanned by physicists to reduce background due to spurious events. There are 35 events in the peak, including an estimated background of 4 events.

In order to convert the data into the form of differential cross sections for η and η' production, we have determined the efficiency of the neutron detector using the π^-p charge-exchange reaction. Data obtained both with and without a trigger from the neutron detector were compared.

The ratio of the differential cross sections obtained with and without the neutron detector, respectively, gave the absolute neutron detection efficiency as a function of neutron kinetic energy. The neutron detection efficiency was found to vary approximately linearly from zero near a neutron kinetic energy of 20 MeV to a constant value of 0.10 in the region from 150 to 1000 MeV. The statistical accuracy of the data in this region of constant efficiency is (15–20)% per 100-MeV interval of kinetic energy. The data are in excellent agreement with a simple model[1] which predicts that, above approximately 150 MeV, all neutrons interacting in the scintillator and producing at least one charged particle are detected. This model predicts that the detection efficiency should vary by less than 5% up to a neutron kinetic energy of 1000 MeV. Thus, if we assume that the detection efficiency remains constant over this region, we have determined the absolute detection efficiency to an accuracy of approximately 7%. This is comparable to the overall normalization error arising from other sources.

The differential cross sections for the reactions leading to η and η', with subsequent decay to two photons, are shown in Fig. 3. The errors shown are statistical only, and do not include the estimated 10% overall normalization uncertainty. In addition to corrections for neutron detector efficiency, a number of other corrections have been applied to the data, the principal of these being for loss of photons emitted at large angles. These losses were approximately 15% for η decay and 30% for η' decay. The corrections were evaluated by a Monte Carlo method. Those η events with $-t \geq 1.0$ (GeV/c)^2 have been rescanned by physicists and identifiable background events have been removed. We estimate that any remaining background is negligible.

The large number of η events in this experiment allows us to demonstrate the existence of structure in the differential cross section near

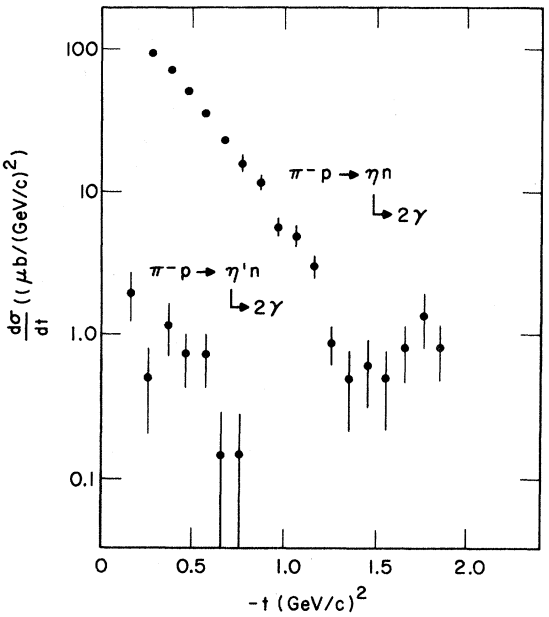

FIG. 3. Differential cross sections for η and η' production at 3.65 GeV/c, with subsequent decay to two photons.

$-t = 1.5$ (GeV/c)^2. (This structure is similar to that obtained from a combination of $\pi^+ p \to \eta \Delta^{++}$ experiments at four-momenta above 2.3 GeV/c.[2]) The data in the region $-t \leq 0.7$ (GeV/c)^2 are consistent with the earlier experiment of Guisan *et al.*,[3] and are in good agreement with the early results of another Argonne experiment in the region at and just above the dip, $1.45 \leq -t \leq 2.2$ (GeV/c)^2.[4]

Analysis of the earlier η production data in terms of Reggeized A_2 exchange yielded values for the effective A_2 trajectory showing a flattening behavior for increasing $-t$, as opposed to the linear trajectory deduced from the charge-exchange reaction.[5] The results reported here are consistent with approximately degenerate, linear ρ and A_2 trajectories, with the A_2 trajectory passing through a value of -1 at $-t = 1.5$ (GeV/c)^2. The data are also consistent with a right-signature (no-compensation) dip if the flattened trajectory passes through zero near this point. The recently proposed dual absorptive model of Harari[6] predicts a dip at $-t \cong 2$ (GeV/c)^2; if the interaction radius is reset to 1.2 F, this model is also consistent with our data.

The total cross sections determined for η and η' production with subsequent decay into two photons are 51 ± 5 and 0.70 ± 0.18 μb, respectively. The shape of the η' cross section has been assumed to be the same as that for η production for the short extrapolation to the minimum value of $-t = 0.02$ (GeV/c)^2. The η' partial cross section may be compared to the results of two experiments yielding the η' total cross section in the same reaction.[7,8] The experiments give consistent results with an average value of 35 ± 8 μb. The η' cross sections are based on the observation of the previously established decay modes of $\pi^+\pi^-\eta$ and $\pi^+\pi^-\gamma$. From these results we deduce the branching ratio for η' decay to $\gamma\gamma$,

$$(\eta' \to \gamma\gamma)/(\eta' \to \text{all}) = 0.020^{+0.008}_{-0.006},$$

in good agreement with a preliminary estimate from a part of the present data,[9] and with a recently reported value of 0.018 ± 0.005 from an experiment performed at 1.6 GeV/c.[10] This value is consistent with a number of theoretical models of the pseudoscalar nonet,[11] but not precise enough to distinguish between, e.g., linear and quadratic mixing.

Two other possible states have been reported at masses near 950 MeV/c^2. The existence of both could affect the reported η' branching ratios. The $\delta(966)$ is a possible 0^+ state with a dominant decay mode[12,13] of $\eta\pi$ and, if narrow, could have an appreciable 2γ decay mode. The M^0 is a possible state with the same dominant decay modes as η', namely the $\pi^+\pi^-\gamma$ and $\pi^+\pi^-\eta$ modes.[14] The $\pi^+\pi^-$ in the $\pi^+\pi^-\gamma$ decay appear to be in a relative s state, however, as opposed to those from η' decay, which form ρ predominantly. Such a state would not have a two-photon decay mode but could add to the apparent total η' production cross section. The constancy of the reported branching ratios between the experiment at 1.6 GeV/c, near threshold, and the present experiment, suggests that any effects due to the presence of δ or M are negligible at the present level of accuracy. η' production is presumably mediated by A_2 exchange, while there is no such high-lying trajectory which can be responsible for δ production. The M^0 has been seen only in production with an associated meson in the reaction $K^- p \to p K^- M^0$ but not in the reaction $K^- p \to \Lambda\eta'$ which shows only η' production. Any effects due to these mesons would be expected to produce an appreciable energy dependence in the reported η' branching ratios.

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Precise Determination of ρ-ω Interference Parameters from Photoproduction of Vector Mesons Off Nucleon and Nuclei

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We have studied ρ-ω interference in di-pion photoproduction in the energy range 5–7 GeV with a total of 630 000 pion pairs from hydrogen, carbon, and lead. The mass spectra show clear interference in the vicinity of the ω mass. A branching ratio $\Gamma_{\omega\to 2\pi}/\Gamma_{\omega\to \mathrm{all}} = (1.22 \pm 0.30)\%$ and a relative phase to the $\rho \to \pi\pi$ amplitude of $96° \pm 15°$ is found, where the errors include model-dependent uncertainties and are twice the size of the statistical errors alone.

The decay $\omega \to 2\pi$ does not conserve G parity. The order of magnitude expected for the $\omega \to 2\pi$ decay amplitude as compared with the $\rho^0 \to 2\pi$ decay amplitude is the fine-structure constant α. Such a result can be visualized as the one-photon-exchange mechanism where $\omega \to \gamma \to \rho \to 2\pi$ with corresponding partial width $\Gamma^{1/2}(\omega \to 2\pi) \simeq 0.1$ $\mathrm{MeV}^{1/2}$, whereas all experiments[1] to date, though not agreeing with each other, give results larger by an order of magnitude. The large difference between these values is the main motivation for a careful investigation of the ω-ρ electromagnetic mixing problems.

Previous experiments were done either with a πp reaction with a large nonresonant background or with a γC reaction where one is seriously handicapped by the problem of the nuclear physics of carbon. In contrast to previous measurements,[2] we have studied ρ-ω interference using three different targets: hydrogen, carbon, and lead. The analysis of the $\pi^+\pi^-$ spectra from each of these elements poses different advantages. Hydrogen has no complication from nuclear physics but has considerable background. With lead, background and incoherent contributions are small whereas a detailed knowledge of nuclear size is required. Carbon provides something of a compromise. One of the main interests of this experiment was to see if compatible $\omega \to 2\pi$ amplitudes could be derived from measurements on such very different nuclei. If so, it would indicate that di-pion photoproduction from nuclei is phenomenologically well understood and is thus a reliable tool for studying ρ-ω mixing.

In this Letter we communicate a summary of the results. Details of the experiment and of the analysis are being published elsewhere.[3]

The data were taken with a 7.4-GeV brems-