Comparison of the Differential Cross-sections for

$$\pi^- p \rightarrow \eta' n \text{ and } \pi^- p \rightarrow \eta n \text{ at } 8.45 \text{ GeV}/c^*$$

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ABSTRACT

The ratio R of the differential cross sections for $\pi^- p \rightarrow \eta' n$ and $\pi^- p \rightarrow \eta n$ has been measured with high statistics and small systematic errors at 8.45 GeV/c. R is generally interpreted as the relative content of nonstrange, ground-state quarks in η' and η . We find that R decreases with increasing $|t|$; however, extrapolation to $t = 0$ gives $R(0) = 0.672 \pm 0.032$ (statistical) ± 0.047 (systematic) for the dominant spin flip cross sections, and $R(0) = 0.500 \pm 0.085 \pm 0.035$ for the spin non-flip, in excellent agreement with results at higher energy.

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It was proposed long ago [1] that the ratio of cross sections for reactions such as

$$\pi^- p \rightarrow \eta n \quad (1)$$

$$\pi^- p \rightarrow \eta' n \quad (2)$$

provides information about the quark content of the η and η' because the strange quark ($s\bar{s}$) content of the η and η' does not couple to the beam pion. It is now generally believed that the situation is more complicated [2]. It has been suggested that the η' (and to a lesser extent the η) may contain admixtures of radial excitations [3,4] and/or glueballs [5,6] which also have small overlap with the wave function of the beam pion and thus behave as inert components in reactions (1) and (2). The ratio of the η' and η cross sections should then measure the relative content of nonstrange quarks in the ground state. [4].

We report here the results of a high-statistics comparison of the differential cross-sections $d\sigma/dt$ for reactions (1) and (2) at 8.45 GeV/c in which the decays

$$\eta \rightarrow \pi^+ \pi^- \pi^0 \rightarrow \gamma\gamma \quad (3)$$

$$\eta' \rightarrow \pi^+ \pi^- \eta \rightarrow \gamma\gamma \quad (4)$$

were observed in the same apparatus, with data collection for (1) and (2) occurring simultaneously. Preliminary results based on half the data have been reported previously [7]. The present sample consists of 5800 η and 3000 η' events, the largest reported sample of reaction (2) at any one energy. The estimated systematic error in the quantity $R = (d\sigma/dt)_{\eta'} / (d\sigma/dt)_{\eta}$, including the uncertainties in the branching fraction (3) and (4), is 7%.

There have recently been published very high statistics data [8] on (1), and data [9] with statistics comparable to ours on (2), in the momentum range 15-40 GeV/c. In that experiment both η and η' were detected via their $\gamma\gamma$ decays, and the systematic error in R is dominated by the present 15% uncertainty [10] in the $\eta' \rightarrow \gamma\gamma$ branching fraction. The opportunity thus exists to study the momentum dependence of $d\sigma/dt$ for (1) and (2) and to combine the results of the two experiment to obtain improved values for both the η'/η ratio and the $\eta' \rightarrow \gamma\gamma$ branching fraction [9].

The present experiment was conducted at the Argonne ZGS with the charged and neutral spectrometer shown in fig. 1 and discussed in more detail elsewhere [11, 12]. This apparatus measured the vector momenta of both charged pions and of both γ 's in the $\pi^+\pi^-\gamma\gamma$ final state; the recoil neutron was not detected. Momentum analysis of the π^+ and π^- was performed in a large-aperture magnetic spectrometer using conventional magnetostrictive spark chambers. Immediately downstream of the charged particle spectrometer was a closely-packed module consisting of a 1.6 radiation length lead converter followed by three magnetostrictive spark chambers which measured the positions of the converted γ showers. An array of 56 lead glass Cerenkov counters then measured the shower energies. Additional magnetostrictive chambers (not shown) upstream of the target measured the direction of the incident π^- beam.

An anticoincidence box of four alternating layers of 1/8 inch scintillator and 1/4 inch lead surrounded the hydrogen target on the four lateral sides. Additional γ -sensitive anticoincidence counters framed the magnet aperture to reject events with extra charged particles

and/or γ 's which would go undetected by the rest of the apparatus. The downstream face of the target box was covered by a thin scintillator H0 containing a small hole for the beam, used in the trigger to signal the presence of at least one charged particle outside the beam. A 30-element scintillator hodoscope H2 downstream of the charged particle spectrometer selected charged particle multiplicity. Two identical 16-element scintillator hodoscopes GHF, GHR on either side of the γ converter module provided the γ trigger: a count in an element of GHR with no count in the corresponding element of GHF indicated a converted shower.

The trigger for most of the data collection runs required: a beam count upstream of the target and no count from a small beam veto counter located at H2; a count in H0; counts in at least two but no more than 3 elements of H2; at least 2 no-yes pairs from GHF-GHR; and no counts from the target veto box or the aperture veto counters. In order to calibrate losses of good events from these trigger requirements (typically 18%) we collected 30% of the data with two weaker triggers: one required only one GHF-GHR no-yes pair, while the other had no upper multiplicity requirement on H2 and allowed any single target veto counter to fire. In calibrating the tight trigger losses from these weak trigger runs we used not only η and η' events, but also $\omega \rightarrow \pi^+ \pi^- \pi^0$ events which have the same topology but are an order of magnitude more plentiful, allowing the (weak) t -dependence of these losses to be determined.

Histograms of $\gamma\gamma$ mass, nucleon missing-mass squared and $\pi^+ \pi^- \gamma\gamma$ effective mass for reactions (1) and (2) are presented in fig. 2.

The arrows in fig. 2 indicate the cuts used for the final data sample. Corrections were made for good events cut in the tails (21% for η , 7% for η') and for the small background under the η and η' peaks (typically 3%) in each bin of t .

The acceptance of the spectrometer for (1) and (2) as a function of momentum transfer t (see fig. 3a) was calculated by a Monte Carlo program which simulated the effects of chamber and counter geometry; cuts on π^+ and γ momenta; $\gamma\gamma$ decay asymmetry; decays or interactions of final state particles; and reconstruction losses due to close proximity of two showers, or of a charged particle and a shower, in the γ detector. We have studied carefully the stability of the acceptance-corrected yield as progressively tighter cuts on event geometry were made to both data and Monte Carlo events, and are satisfied that the effects of present cuts are understood. In general the η data were more sensitive to such geometry effects because of the tighter collimation of decay products.

The estimated systematic error in R of 7% was obtained by adding quadratically the estimated relative uncertainties in the acceptance calculation (5%), trigger loss correction (2.5%), tail cuts (2.3%) and branching fractions [10] (3.6%). There is an additional overall normalization uncertainty of 7% arising from factors such as γ conversion efficiency which are common to both η and η' .

Differential cross sections $d\sigma/dt$ for reactions (1) and (2) at 8.45 GeV/c, corrected for unseen decay modes [10], are presented in fig. 3b, while the ratio R as a function of $t' = t - t_{\min}$ is shown in fig. 3c. The shapes of $d\sigma/dt$ for η and η' are qualitatively similar, both showing a forward turnover. However, the η' $d\sigma/dt$ has a steeper slope,

so that R decreases by a factor of 4 in the interval $0.0 \leq -t' \leq 1.0$. There is an abrupt break to a much shallower slope near $t' = -1.0$ for both η and η' , with R once again roughly consistent with its value near $t' = 0$. The integrated cross sections for $|t'| < 1(\text{GeV}/c)^2$, corrected for unseen decay modes, are $36.4 \mu\text{b}$ and $14.6 \mu\text{b}$ for (1) and (2) respectively, subject to the systematic errors discussed above.

We have fit $d\sigma/dt$ data for η and η' from this experiment, and from refs. 8, 9, and 11, to the forms

$$\frac{d\sigma}{dt} = (A - Bt')e^{ct'} \quad (5)$$

$$\frac{d\sigma}{dt} = A(1 - gct')e^{ct'} \quad (6)$$

where A and B are the absolute squares of the nucleon spin nonflip and flip amplitudes at $t' = 0$, and $g = B/Ac$ is the ratio of total cross sections for flip and nonflip. The use of a common exponential slope c for flip and nonflip has been shown [8] to be valid for (1) by very high statistics η data. All fits have been performed in the interval $0.0 \leq -t' \leq 0.8(\text{GeV}/c)^2$. For our data at $8.45 \text{ GeV}/c$ we obtain $A_\eta(A_{\eta'}) = 44.4 \pm 4.8(21.2 \pm 2.8)\mu\text{b}/(\text{GeV}/c)^2$; $B_\eta(B_{\eta'}) = 1405 \pm 75(920 \pm 60)\mu\text{b}/(\text{GeV}/c)^4$; $c_\eta(c_{\eta'}) = 6.82 \pm 0.12(8.69 \pm 0.18)(\text{GeV}/c)^{-2}$.

Results of fits to the form (5) for our data are shown as solid curves in figs. 3b, 3c, while the corresponding $40 \text{ GeV}/c$ result is shown as a dashed line in fig. 3c. The momentum dependence of the shape parameters c , B/A and g for η and η' are displayed in fig. 4. It is clear that the exponential slope c for η' is larger than that for η in the momentum range $8.45 < p < 40 \text{ GeV}/c$, but increases more slowly with increasing p . Thus R shows less t -dependence at higher

momentum (fig. 3c). The ratios B/A are momentum-independent within experimental errors; however, B/A is about 25% higher for η' than for η . This relatively smaller nonflip content for η' is responsible for the turnover in R at small t' . The ratio g decreases slowly with momentum, and is the same within errors for η and η' .

Because of the momentum dependence of c , meaningful measures of relative quark content must be obtained by extrapolation to $t' = 0$. We display in figs. 4a, 4b the quantities $R_{NF} = (p_{\eta}^*/p_{\eta'}^*) A_{\eta}/A_{\eta'}$ and $R_F = (p_{\eta}^*/p_{\eta'}^*) B_{\eta}/B_{\eta'}$ for nonflip and flip respectively. The CM momentum ratio $p_{\eta}^*/p_{\eta'}^*$ ($= 1.05$ at 8.45 GeV/c) corrects for the slightly different available phase space. The values for this experiment are $R_{NF} = 0.500 \pm 0.085 \pm 0.035$ and $R_F = 0.681 \pm 0.077 \pm 0.048$ (where the second set of errors is systematic), very consistent with the results of ref. 9. It has been argued that R_F is the better measure of quark content because the flip amplitude dominates, and because the nonflip amplitudes are likely to be complicated by absorption effects [5].

It is possible to obtain a more precise value of R_F by correcting the total cross section for differences in shape. Integration and manipulation of (5) gives

$$(B_{\eta}/B_{\eta'})_{\sigma} = [(c_{\eta}/c_{\eta'})^2] [(1+g_{\eta}^{-1})/(1+g_{\eta'}^{-1})] \sigma_{\eta}/\sigma_{\eta'} \quad (7)$$

where, as can be seen from fig. 4, the main contribution to the uncertainty in the correction terms in square brackets comes from c_{η} . The resulting quantity $R_{F\sigma} = (p_{\eta}^*/p_{\eta'}^*) (B_{\eta}/B_{\eta'})_{\sigma}$ is shown in fig. 5c for total cross section data from this experiment and from that of ref. 9; the error flags include the correction uncertainties. We find for this experiment $R_{F\sigma} = 0.672 \pm 0.032 \pm .047$, while for the averaged data of ref. 9 $R_{F\sigma} = 0.673 \pm 0.024 \pm .101$, in excellent agreement.

We may also combine the results of the two experiments to obtain an improved value [9] for the branching fraction $f = (\eta' \rightarrow \gamma\gamma)/(\eta' \rightarrow \text{all})$ by assuming the R_{FG} is indeed independent of energy; this gives $f = 0.0200 \pm 0.0018$.

Finally, we remark that there is good a priori reason to expect $c_{\eta'}$ to be smaller than c_{η} , contrary to what is observed. The idea of semi-local duality [13] and empirical evidence [14] suggests that c scales like $\log(s/m^2)$, with higher-mass states having shallower slopes. On this basis the η data in fig. 4a predict $c_{\eta'} \approx 5.2(7.6)$ at 8.45(40) GeV/c. We suggest that the observed steeper η' slope could well result from an admixture of radial excitation which would increase the effective size of the η' , making it more difficult for the η' to hold together at larger momentum transfers.

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REFERENCES

- [1] G. Alexander, H.J. Lipkin and F. Scheck, Phys. Rev. Lett. 17 (1966) 412.
- [2] See, e.g., S. Okubo and K. Jagannathan, Phys. Rev. D15 (1977) 177.
- [3] H.J. Lipkin, Phys. Lett. 67B (1977) 65.
- [4] I. Cohen and H.J. Lipkin, "A Phenomenological Model for Pseudo-scalar Meson Mixing", Argonne preprint ANL-HEP-PR-78-41 (1978).
- [5] N.H. Fuchs, Phys. Rev. D14 (1976) 1912.
- [6] R.H. Capps, Phys. Rev. D17 (1977) 1862.
- [7] K.W. Edwards et al., paper submitted to 18th Intern. Conf. on High Energy Physics (Tbilisi, 1976).
- [8] W.D. Apel et al., Nucl. Phys. B152 (1979) 1.
- [9] W.D. Apel et al., Phys. Lett. 83B (1979) 131.
- [10] Particle Data Group, Review of Particle Properties, Phys. Lett. 75B (1978) 1.
- [11] M.H. Shaevitz et al., Phys. Rev. Lett. 36 (1976) 5.
- [12] M.H. Shaevitz, Ph.D. thesis, Ohio State University, 1975 (unpublished).
- [13] P. Hoyer, R.G. Roberts and D.P. Roy, Nucl. Phys. B56 (1973) 173.
- [14] M.J. Corden et al., "Production of A_2^0 and $\omega^*(1675)$ in the Reaction $\pi^- p \rightarrow \pi^+ \pi^- \pi^0 \eta$ at 12 and 15 GeV/c" Rutherford Laboratory preprint RL-77-097/A (1977).

FIGURE CAPTIONS

- Fig. 1. Plan view of the charged and neutral spectrometer. The scale along the beam direction has been expanded slightly for clarity.
- Fig. 2. Histograms of: (a), (b) $\gamma\gamma$ mass for reactions (1) and (2); (c), (d) nucleon missing mass squared for reactions (1) and (2); (e) $\pi^0\pi^+\pi^-$ mass for reaction (1); (f) $\eta\pi^+\pi^-$ mass for reaction (2). Arrows indicate cuts for final sample.
- Fig. 3. (a) Spectrometer acceptances for reactions (1) and (2). (b) Differential cross sections for (1) and (2). (c) Ratio R as a function of t . The curves through the data are discussed in the text. Error flags indicate statistical errors only.
- Fig. 4. Momentum dependence of $d\sigma/dt$ shape parameters for reactions (1) and (2). Quantities plotted here are independent of normalization. $\eta(\eta')$ data are shown as shaded (open) points. The 6 GeV/c data are from ref. 11, while the 15-40 GeV/c data are from refs 8 and 9.
- Fig. 5. Extrapolations of R to $t' = 0$ for this experiment (circles) and data of ref. 9 (squares). (a) Nucleon spin nonflip; (b) nucleon spin flip; (c) Nucleon spin flip from corrected total cross section. Systematic errors are not included in the error flags.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5