ω Production in $\pi^+d \rightarrow pp\pi^+\pi^-\pi^0$ at 6.95 GeV/c*

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We report on the analysis of the reaction $\pi^+n \rightarrow \omega^0p$ at 6.95 GeV/c. The absence of a dip in the differential cross section at $t \simeq -0.6$ (GeV/c)^2 and the nonzero values for the ω^0 spin-density matrix element ρ_{00} for $|t|<1.4$ (GeV/c)^2 indicates that an unnatural-parity contribution to this process is still important at this energy. A simple Regge-pole model is found to represent the general form of the data.

The reaction $\pi^+n \rightarrow \omega^0p$ has been studied at 6.95 GeV/c. The results are found to be adequately described by a simple Regge-exchange model. The significant features of the data are a pronounced drop in the differential cross section in the forward direction, the absence of a dip at the wrong-signature zero of the ρ trajectory, and the large value of ρ_{00} indicating a contribution to the process from an unnatural-parity exchange.

This analysis is based on an exposure in the Argonne National Laboratory–Midwestern Universities Research Association 30-in. deuterium bubble chamber to a 6.95-GeV/c π^+ beam. Measurement of about 30 000 three- and four-prong events has yielded a final sample[1] of 5471 events in the channel $\pi^+d \rightarrow pp\pi^+\pi^-\pi^0$, of which 369 ± 20 events are produced by the two-body process $\pi^+n \rightarrow \omega^0p$.

The $\pi^+\pi^-\pi^0$ mass distribution below 1 GeV/c^2 is shown in Fig. 1.[2] These data have been fitted by a phase-space distribution modified by s-wave relativistic Breit-Wigner functions.[3] The phase-space distribution in turn was approximated by a standard phase space multiplied by a polynomial function in the 3π mass. Our experimental mass resolution of 25.1 ± 2.5 MeV/c^2 (full width at half-maximum) was folded in during the fitting to yield mass, M, and width, Γ, values for the ω^0 of $M = 784.0 \pm 1.4$ MeV/c^2 and $\Gamma = 14.0 \pm 5.1$ MeV/c^2, respectively. The background in the ω^0 mass region, 0.74-0.83 GeV/c^2, was determined from this fit to be $30.4^{+4.5}_{-13.5}$ events, an 8.2% correction.

The cross section for $\pi^+n \rightarrow \omega^0p$, corrected for unseen decay modes of the ω^0,[4] was determined to be 86.4 ± 12.8 μb. This value of the cross section was calculated using only the four-prong data, and is in agreement with the value derived from the three-prong data which has somewhat larger errors. Corrections for the effect of the Pauli exclusion principle on the two-nucleon final state at low momentum transfers[5] yielded finally

$$89.6 \pm 13.3 \leq \sigma_{\pi^+n \rightarrow \omega^0p} \leq 96.2 \pm 14.2\ \mu\text{b},$$

where the lower and upper limits were for 100% spin flip and spin nonflip at the nucleon vertex, respectively.

We have used the combined three- and four-prong data in the following analysis. The mass distributions, differential cross sections, and

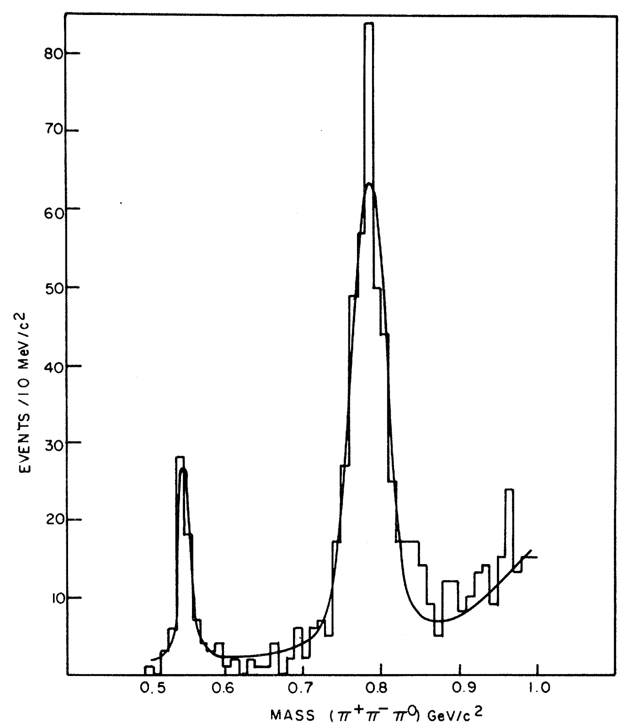

FIG. 1. Invariant mass of $\pi^+\pi^-\pi^0$ in the η^0 and ω^0 mass region. The solid curve is a fit of Breit-Wigner forms plus background yielding mass and width values for the ω^0.

density-matrix elements have been checked for consistency between the three-prong, four-prong, and combined data samples. Differences between these data samples were all within one standard deviation with the single exception of $\mathrm{Re}\rho_{10}$ for $|t|<0.1$ (GeV/c)^2. The combined-sample value for $\mathrm{Re}\rho_{10}$ is shown in Fig. 2(c), however, the four-prong value is $\mathrm{Re}\rho_{10}=-0.01\pm0.07$ for this t range. The large effect of the background in this t interval was believed to be the cause of this discrepancy.

The differential cross section and density-matrix elements are shown in Figs. 2 and 3. The data have been corrected for Pauli exclusion effects[5] and for background.

The differential cross section and the $J^P=1^-$ density matrix elements were determined for two overlapping background regions selected with 3π masses above the ω^0 mass interval. The differential cross sections for the two background regions were found to be well described by the exponential dependence $\exp[(7.5\pm0.5)t]$. This t dependence for the background was assumed to describe the background in the ω^0-mass region. The small number of events available in the control regions, and the lack of events with 3π masses less than the ω^0, make this assumption somewhat uncertain. By choosing two background regions above the ω^0 we determined that the slope of the differential cross section, outside the ω^0 mass region, was a slowly varying function of the 3π mass. We believe, therefore, that we have a reasonable parametrization of the background contribution to the differential cross section in the ω^0 mass interval.

A similar procedure was applied to the density-matrix elements. Corrections were found to be necessary only in the $|t|$ interval 0.0-0.1 (GeV/c)^2. The corrected density-matrix elements are shown dotted in Fig. 2. These corrections to the ω^0 density-matrix elements include only the statistical error estimates. At the present level of statistics the large uncertainties involved in determining the dependence of these terms on the 3π mass makes these corrections somewhat speculative.

We note that after background subtraction and differential cross section in the present data [Fig. 3(c) and 3(d)] has a 3- to 7-standard-deviation dip in the forward direction for spin nonflip and spin flip at the nucleon, respectively. The published experiments are presently split between those favoring a constant cross section for $|t|<0.2$,[6] and those favoring a dip.[7] We note that the former experiments[6] have a larger percentage of background in the ω^0 mass region than the latter,[7] and it is not clear that this background was completely accounted for in determining the differential cross sections. A forward dip in the differential cross section would be inconsistent with one absorption model,[8] but is in agreement with the predictions of standard Regge models.[9-12]

Past interest in $\pi^+n\to\omega^0p$ has focused on the lack of a dip in the differential cross section at the wrong-signature point, $\alpha_\rho=0$, of the ρ trajectory which is expected to contribute to this process.[9,10,13-15] There is no evidence for a dip in our data at $t\sim-0.6$ (GeV/c)^2 (see Fig. 3),[16] and the data can be well described by an exponential in the t interval -0.3 to -0.8 (GeV/c)^2.

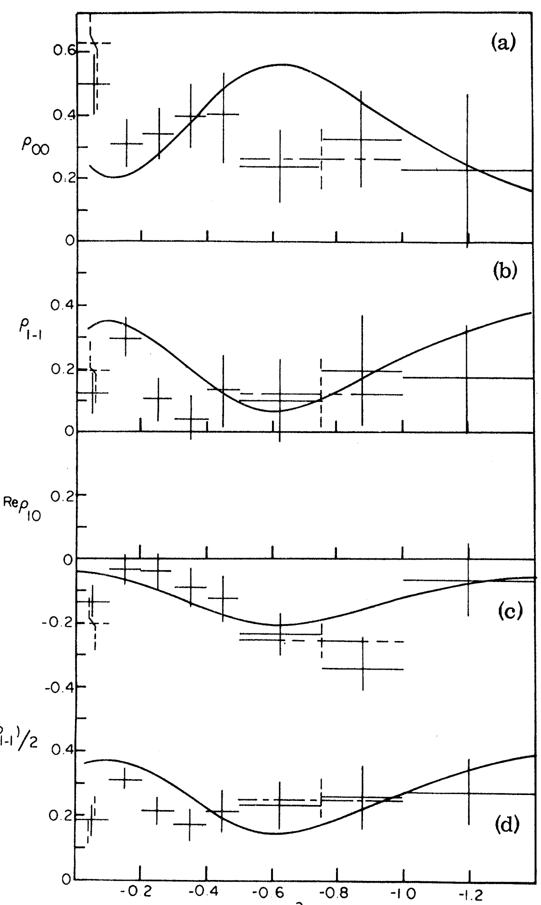

FIG. 2. Density-matrix elements of the ω^0: (a) ρ_{00}, (b) ρ_{1-1}, (c) $\mathrm{Re}\rho_{10}$, and (d) $\sigma_1^+=(\rho_{11}+\rho_{1-1})/2$. The dotted point in the $|t|$ interval 0.0-0.1 (GeV/c)^2 has been corrected for background. No corrections to background were required for $|t|>0.1$ (GeV/c)^2. The dotted point between $|t|=0.5$-1.0 (GeV/c)^2 is the average of the solid points in the same t interval.

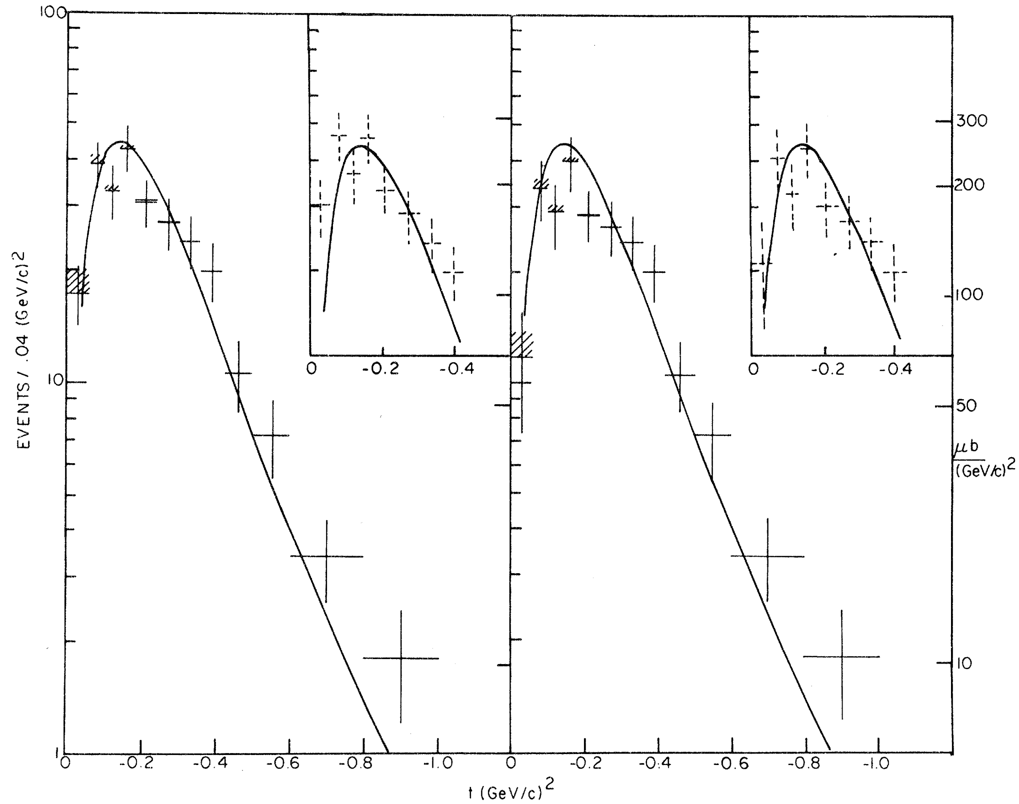

FIG. 3. Differential cross section for $\pi^+n\rightarrow\omega^0p$. (a) The solid crosses are the uncorrected data; the cross-hatched portion includes the correction for pure spin flip at the nucleon. (b) These data have been corrected for pure spin nonflip at the nucleon; no background subtraction has been applied. (c), (d) Same as (a), (b) with subtraction of background as explained in the text. The solid curves are the prediction of a Regge-exchange model using ρ, ρ', and B exchanges.

The feature is inconsistent with models utilizing pure ρ Regge exchange,[11] and also appears to be inconsistent with the ρ-plus-strong-cut model.[4]

The ω^0 density-matrix elements are presented in Fig. 2 and Table I.[17] We note that in a simple exchange model only unnatural-parity exchange, for example, B-meson exchange, will contribute[12,13,18] to ρ_{00}; the simple exchange of a ρ meson[18] yields $\rho_{00}=0$ for all values of t. Our data are consistent with a nonzero ρ_{00} for all values of $|t|<1.4$ (GeV/c)^2 [see Fig. 2(a)], and suggest a large unnatural-parity contribution to the process.

In addition to the standard density-matrix elements we have plotted $\sigma_1^+=(\rho_{11}+\rho_{1-1})/2$ as suggested by Högaasen and Lubatti.[13,15] For simple ρ and B exchange, σ_1^+ will vanish at zeros of the

Table I. ω^0 density-matrix elements in Jackson and helicity frames. No correction for background has been made to these data.

$\|t\|$ (GeV/c)^2	Jackson Frame ρ_{00}	ρ_{1-1}	Reρ_{10}	Helicity frame ρ_{00}	ρ_{1-1}	Reρ_{10}
0.0-0.1	0.50±0.10	0.12±0.07	−0.13±0.05	0.50±0.10	0.12±0.07	0.10±0.05
0.1-0.2	0.31±0.07	0.29±0.06	−0.03±0.04	0.17±0.07	0.22±0.06	0.10±0.04
0.2-0.3	0.34±0.08	0.10±0.07	−0.04±0.05	0.29±0.09	0.08±0.07	0.05±0.05
0.3-0.4	0.40±0.10	0.04±0.07	−0.09±0.06	0.32±0.10	0.01±0.08	0.10±0.05
0.4-0.5	0.39±0.15	0.13±0.11	−0.12±0.07	0.21±0.13	0.04±0.13	0.13±0.07
0.5-1.0	0.26±0.10	0.12±0.11	−0.26±0.05	0.19±0.11	0.08±0.09	0.24±0.06
1.0-1.4	0.23±0.24	0.18±0.18	−0.06±0.11	0.14±0.15	0.14±0.20	0.03±0.14

ρ contribution. Our data are consistent with σ_1^+ being nonzero at the wrong-signature point of the ρ; see Fig. 2(d). However, the poor statistics in this t range necessitates the use of large t bins and the analysis yields large uncertainties in the density-matrix elements. With these limitations we are unable to exclude the possibility of a zero in the σ_1^+ term in this t region.

The curves drawn on the differential cross sections (Fig. 3) and the density-matrix elements (Fig. 2) result from a simple Regge-exchange model involving ρ, ρ', and B-meson exchanges.[12] The curves, obtained using the parameters of Ref. 12 from a fit to data at 3.65, 4.19, and 5.1 GeV/c and the present experiment, describe the general form of the data, reproducing the forward dip in $d\sigma/dt$, the absence of a dip at $t \sim -0.6$ (GeV/c)^2, and the t dependence of the density matrix elements ρ_{00}, ρ_{1-1}, and Reρ_{10}. The addition of the ρ'-exchange[12] term to a $\rho + B$ model describes the σ_1^+ data [Fig. 2(d)], and is consistent with the data being nonzero at the wrong-signature point of the ρ.[12,13]

In conclusion, our analysis of the process $\pi^+ n \to \omega^0 p$ at 6.95 GeV/c is consistent with a dip in $d\sigma/dt$ in the forward direction and with the absence of a dip at $t \sim -0.6$ (GeV/c)^2. This is inconsistent with simple Regge-exchange models (with wrong-signature zeros) employing only ρ exchange. The nonzero values of ρ_{00} for all t values studied indicates that a substantial unnatural-parity exchange is still required at this energy. The data are found to be consistent with a Regge model including ρ, ρ', and B-meson exchanges.

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[1]Events were scanned for one or two identifiable protons in three- and four-prong events, respectively. Accepted events were consistent with scan table ionization. The data have spectator-proton momentum cuts of ≤ 0.3 GeV/c for the four-prong data and ≤ 0.1 GeV/c in the plane for the three-prong data. An overall χ^2 probability cut of 5% was applied to the data. Events fitting π^0 constrained to 2γ conversions in the liquid or plates of the chamber were accepted only with fitted γ momenta exceeding those estimated in the scan table. The data contains events with proton momenta <1.5 GeV/c.

[2]The sharp peak at the ω^0 mass, not well fitted by the curve, comes from the three-constraint (3C) events with the π^0 fitted to 2γ conversions. The mass resolution for these events was much better than for the 1C fits. These 3C data reflect the true width of the ω^0 rather than the Gaussian-like mass peak characteristic of the 1C data.

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[16]The differential cross section for $\pi n \to \omega^0 p$ has been plotted in various width bins for $0.4 < |t| < 0.8$ (GeV/c)^2. There is no evidence for a dip at $t \sim -0.6$ (GeV/c)^2 in these data even for t bins as small as 0.04 (GeV/c)^2. Shallow dips can not be excluded; however, the data is greater than 4 standard deviations from being zero in the t range $0.54 < |t| < 0.66$ (GeV/c)^2.

[17]The density-matrix elements referred to in the text are calculated in the Jackson frame. The values calculated in the helicity frame are included in Table I for completeness.

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