"ELASTIC" PHOTOPRODUCTION OF ρ^0 AND ϕ^0 MESONS FROM HYDROGEN‡

C. BERGER ‡‡, N. MISTRY, L. ROBERTS, R. TALMAN and P. WALSTROM
Laboratory of Nuclear Studies, Cornell University, Ithaca, New York 14850, *USA*

Received 24 April 1972

Cross-sections are presented for the "elastic" processes $\gamma + p \rightarrow \rho^0 + p$ and $\gamma + p \rightarrow \phi^0 + p$ at 8.5 GeV. The inelastic contribution to ρ^0 and ϕ^0 photoproduction from hydrogen was eliminated by requiring a proton recoil in coincidence with the pair-spectrometer. Detailed mass-fits were made to the rho data using a Söding interference model to obtain the final "elastic" cross-sections.

Measurements of ρ^0 and ϕ^0 photoproduction from hydrogen using "counter" techniques [1-3] for detection of the vector meson decay products alone are subject to uncertainty due to the unknown "inelastic" contribution to the production processes. We have used a proton recoil hodoscope in coincidence with the pair-spectrometer described previously [1], to eliminate the inelastic processes. The scintillation counter hodoscope, with an angular resolution of ±25 mrad, was place below the hydrogen target, the pair spectrometer being tilted vertically to vary the production angle from 0° to a maximum of 0.083 radians. The ϕ^0 and ρ^0 production azimuths were determined by spark-chamber reconstruction of the trajectories of the decay meson-pairs. Coplanarity of the recoil proton and vector meson was the criterion for two-body production ‡‡‡. The efficiency of the counter hodoscope was measured at the various angles using an additional large scintillation counter below the hodoscope. In each case the efficiency was equal to the expected "geometrical" efficiency of 95% to within ±2%. At the highest angles, for rho production, a sheet of lead was used to shield the hodoscope from soft radiation. At these angles the proton kinetic energies were sufficient to allow them to penetrate the lead. A correction of 3.5% was necessary to account for nuclear absorption of the protons in the lead for these data.

‡ Work supported by the National Science Foundation.
‡‡ Supported by Bundesministerium für Wissenschafft und Bildung.
Present address: Physikalisches Institut der Universitaet Bonn, Germany.
‡‡‡ A Monte-Carlo calculation of the coplanarity distribution for production of (N^* + vector meson) gives a FWHM of ~ 1.2 radian, where the recoil proton is detected.

Rho-production in coincidence with recoil protons was measured at $\langle t \rangle$ = - 0.076 GeV^2, - 0.181 GeV^2, - 0.377 GeV^2 and - 0.515 GeV^2, at an average energy E_ρ = 8.47 GeV. The pion-pair mass-spectrum was measured at eight values between $\langle m_{\pi\pi} \rangle$ = 500 MeV and 910 MeV at each of the above angles. The mass spectrum at 0° without the proton coincidence was also measured. The inelastic fraction at each mass is shown in table 1 as a function of $\langle t \rangle$. Smooth extrapolations are used to obtain the inelastic contribution at 0°. *All subsequent data referred to below are the "elastic" data after subtraction of the inelastic contribution.*

Fig. 1 shows the slope parameter b of the cross-section $d^2\sigma/dt dm$ in the usual expression $A \exp(bt)$, as a function of the mass $\langle m_{\pi\pi} \rangle$. Data from the SLAC hydrogen bubble chamber experiment [4] are shown for comparison. The b-value at $\langle m_{\pi\pi} \rangle = m_\rho$ may be considered to be the slope of the "pure" rho, since all Drell-type and interference terms vanish at that point. (See below.)

The mass-spectrum at each t was separately fitted using the Söding model [5] for the interference between rho- and Drell-type amplitudes for pion-pair photoproduction. The Drell amplitude was calculated using the pion-nucleon total cross-section at t = 0, and the relative t-dependence of the Drell cross-section was left free as a coefficient, D. The Drell amplitude includes a factor which avoids "double-counting" of the rho [6] †. The rho cross-section is obtained from these fits, where fixed values m_ρ = 770 MeV, Γ_0 = 130 MeV were used as standard values, as averages from previous work [7] ‡. Fig. 2 shows

† The explicit factor multiplying the Drell *amplitude* is $(m_\rho^2 - m^2)/(m_\rho^2 - m^2 + im\Gamma(m))$.

Table 1
Inelastic fraction ζ in ρ^0 photoproduction. Momentum transfer is in GeV^2.

$\langle m_{\pi\pi}\rangle$	$\zeta(t=-0.076)$	$\zeta(t=-0.181)$	$\zeta(t=-0.377)$	$\zeta(t=-0.515)$
495	0.08 ± 0.08	0.52 ± 0.15	0.58 ± 0.15	0.65 ± 0.10
609	0.05 ± 0.05	0.28 ± 0.07	0.37 ± 0.10	0.56 ± 0.11
658	0.10 ± 0.05	0.25 ± 0.05	0.28 ± 0.06	0.24 ± 0.07
708	0.01 ± 0.05	0.09 ± 0.03	0.26 ± 0.06	0.35 ± 0.05
758	0.04 ± 0.05	0.15 ± 0.04	0.24 ± 0.04	0.23 ± 0.03
809	0.10 ± 0.06	0.21 ± 0.03	0.28 ± 0.08	0.25 ± 0.03
858	0.0 ± 0.10	0.26 ± 0.10	0.43 ± 0.14	0.40 ± 0.15
911	0.33 ± 0.30	0.44 ± 0.30	0.31 ± 0.30	0.20 ± 0.20

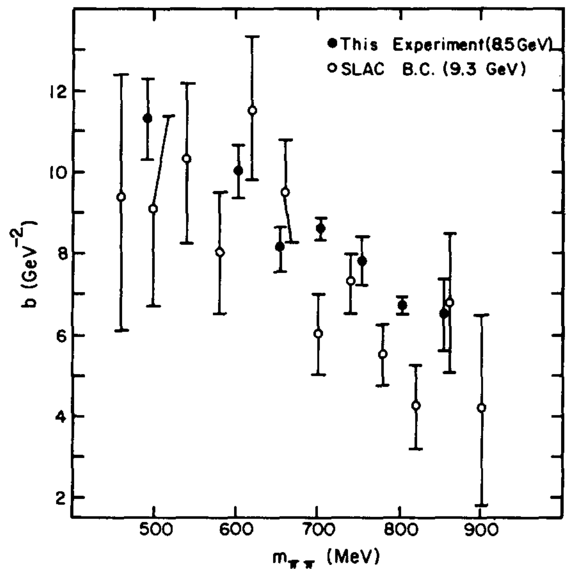

Fig. 1. The slope parameter b(GeV^{-2}) as a function of the mass $\langle m_{\pi\pi}\rangle$. Data from the SLAC hydrogen bubble chamber [5] are shown for comparison.

the mass-spectra and resultant fits to the data ‡.

The t-dependence of the elastic rho cross-section is shown in fig. 3(a). The best fit to the data using the expression

$$d\sigma/dt\,(\mu b/\mathrm{GeV}^2) = A\,\exp(bt)$$

is given by the values $A = (98 \pm 6)\ \mu b/\mathrm{GeV}^2$, $b = (7.4 \pm 0.5)\ \mathrm{GeV}^{-2}$ at $\langle E\rangle_{\pi\pi} = 8.5$ GeV. (The error in b includes a systematic error of ±2% in the energy). ‡‡ These values do not differ significantly from previous values obtained in counter experiments [1,3] that included inelastic contamination. The slope parameter b given above differs from the SLAC bubble-chamber result at 9.3 GeV: $b = (6.5 \pm 0.3)\ \mathrm{GeV}^{-2}$, obtained using the Söding-model for extraction of the rho cross-sections. We have also fitted the data with the expression $d\sigma/dt\,(\mu b/\mathrm{GeV}^2) = A\,\exp(b_1 t + b_2 t^2)$, the results being

$$A = (110 \pm 8)\ \mu b/\mathrm{GeV}^2\,,$$

$$b_1 = (9.0 \pm 0.8)\ \mathrm{GeV}^{-2}\,,$$

$$b_2 = (3.2 \pm 1.6)\ \mathrm{GeV}^{-4}\,.$$

Fig. 3(b) shows the relative t-dependence of the Drell cross-section as obtained from the mass-spectrum fitting. The data have been normalized to unity at $t = 0$. The smooth curve is the predicted t-dependence given by the expression

$$D(t) = D_0\,\exp(9.0t + 2.4t^2)$$

where the exponential factor is the t-dependence of pion-nucleon elastic scattering [9], and D_0 is a normalizing constant such that $D(0) = 1.0$. The t-dependence of the data is in excellent agreement with the theory. The absolute magnitude of the Drell cross-section obtained from the data is less than the predicted value by a factor (0.82 ± 0.22). This factor is sensitive to the rho shape and width. The entire π-pair photoproduction in the region of the rho-meson appears to be well-described by the theory; in particular, the skewing of the mass-spectrum towards low masses, and the reduced skewing at large t.

We remark that in view of the current interest in the variation of the slope of the rho-production cross-section with q^2 (in electro-

‡ $m_\rho = 770$ MeV, $\Gamma_\rho = 130$ MeV have been chosen as "standard" values in comparing results of various rho-photoproduction experiments.

‡ The data were also fit using ρ-ω interference parameters from published data. (For recent values, see ref. [8].) The results of these fits did not differ significantly from the results quoted here.

‡‡ This value for b is lower than the value 8.1 GeV^{-2} presented at the Cornell conference [8] due to an upward correction in our mean energy. This was due to the variation, over our aperture, of the cross section which is weighted toward high energy.

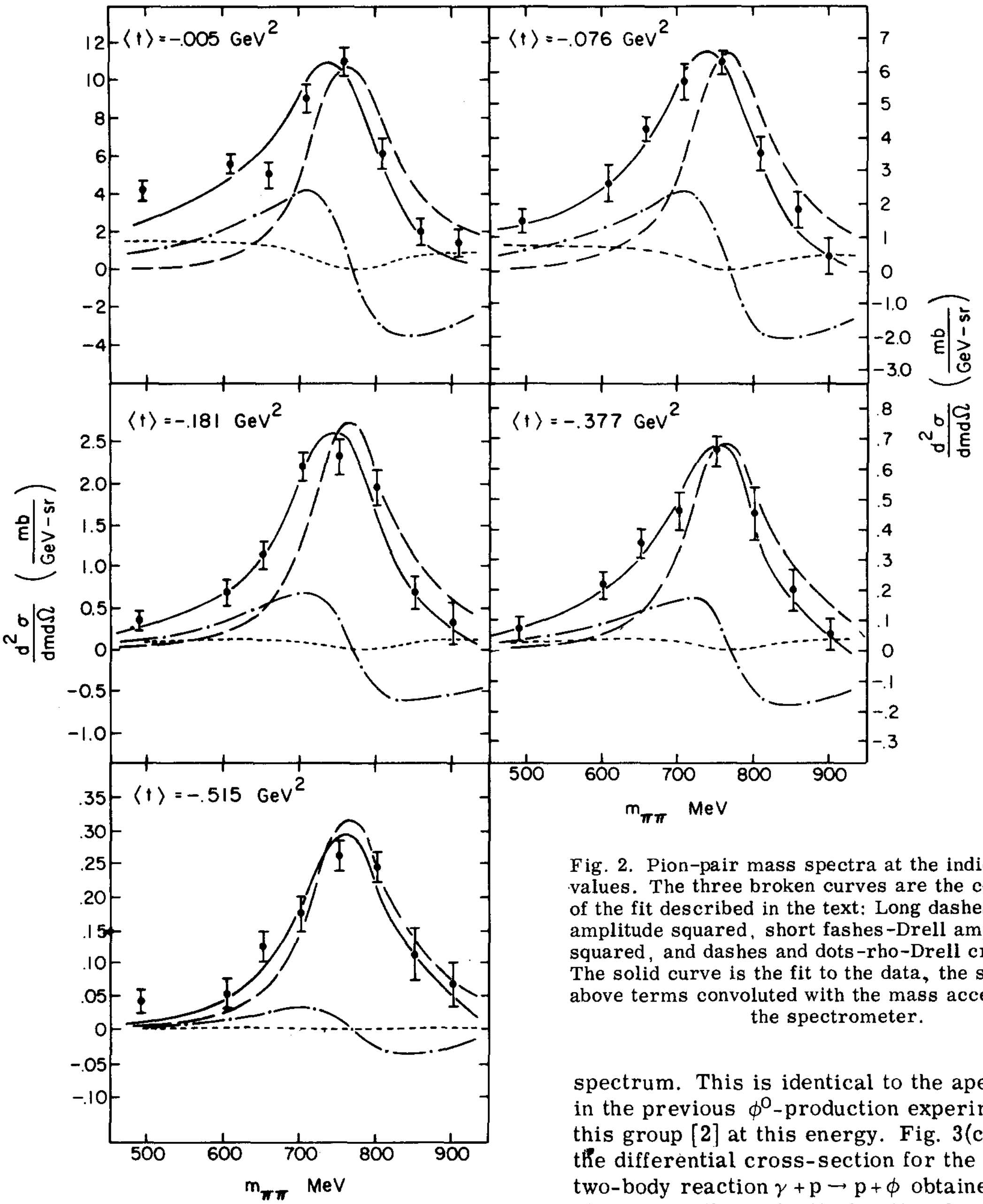

Fig. 2. Pion-pair mass spectra at the indicated t-values. The three broken curves are the components of the fit described in the text: Long dashes-rho amplitude squared, short fashes-Drell amplitude squared, and dashes and dots-rho-Drell cross term. The solid curve is the fit to the data, the sum of the above terms convoluted with the mass acceptance of the spectrometer.

production) it is important that the slope parameter at $q^2 = 0$ (photoproduction) be known unambiguously.

The inelastic fraction $\zeta(t)$ in ϕ^0-production is shown in table 2. This represents the inelastic contribution within the energy acceptance of the pair-spectrometer which has a FWHM of 1.5 GeV, centered at 8.5 GeV, and with an end-point energy of 9.8 GeV for the bremsstrahlung spectrum. This is identical to the aperture used in the previous ϕ^0-production experiments of this group [2] at this energy. Fig. 3(c) shows the differential cross-section for the "elastic" two-body reaction $\gamma + p \rightarrow p + \phi$ obtained by eliminating the inelastic fraction described above The data points include data from ref. [2], with the inelastic contribution eliminated using $\zeta(t)$. The points at 0^0 are obtained by extrapolating the inelastic fraction in table 2, giving $\zeta(0^0) = 0.14 \pm 0.08$. The t-dependence of the *combined data* may be characterized by the following expression:

$$(d\sigma/dt)\ \mu b/GeV^2 = (2.85 \pm 0.20) \exp(5.4 \pm 0.3)t\ .$$

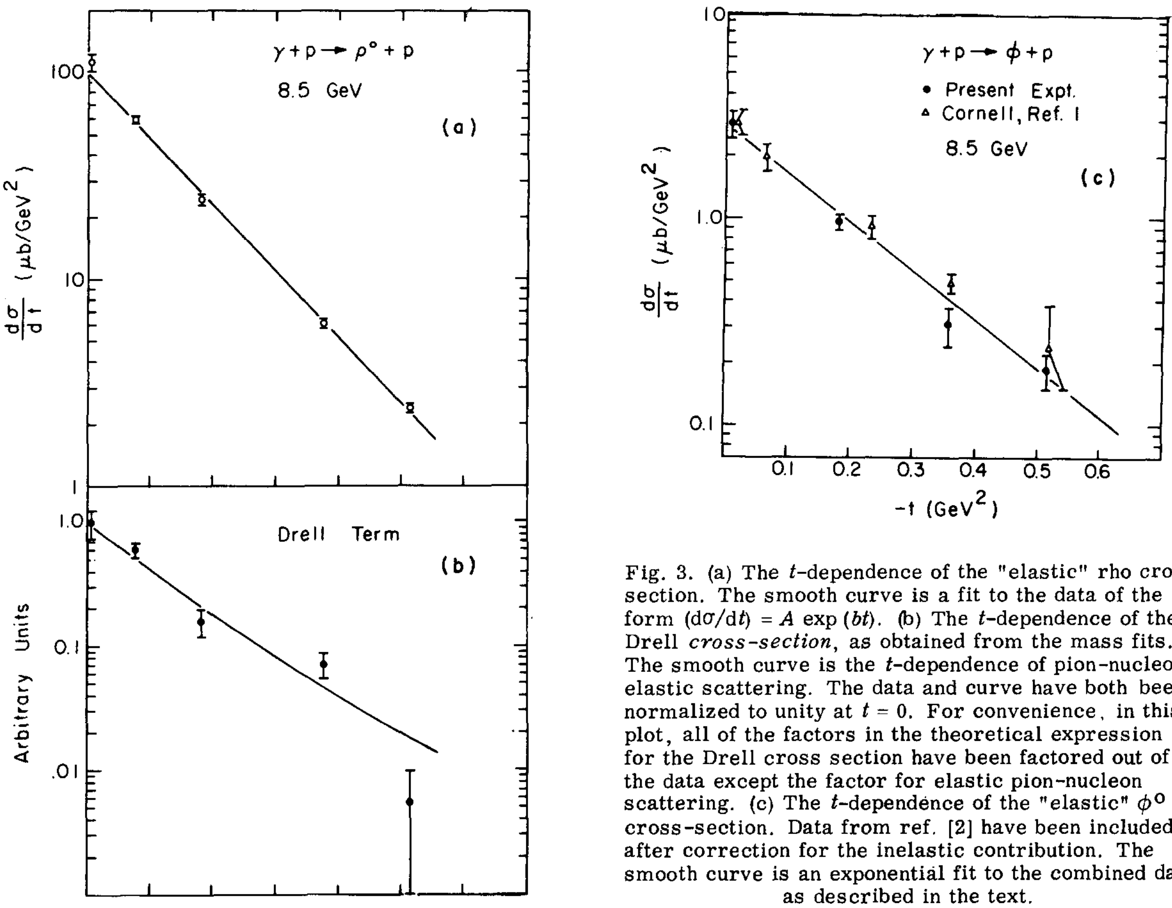

Fig. 3. (a) The t-dependence of the "elastic" rho cross-section. The smooth curve is a fit to the data of the form $(d\sigma/dt) = A \exp(bt)$. (b) The t-dependence of the Drell *cross-section*, as obtained from the mass fits. The smooth curve is the t-dependence of pion-nucleon elastic scattering. The data and curve have both been normalized to unity at $t = 0$. For convenience, in this plot, all of the factors in the theoretical expression for the Drell cross section have been factored out of the data except the factor for elastic pion-nucleon scattering. (c) The t-dependence of the "elastic" ϕ^0 cross-section. Data from ref. [2] have been included, after correction for the inelastic contribution. The smooth curve is an exponential fit to the combined data as described in the text.

Table 2
Inelastic fraction in ϕ photoproduction.

t (GeV^2)	ζ
-0.17	0.16 ± 0.04
-0.33	0.14 ± 0.05
-0.46	0.19 ± 0.08

We would like to point out that the observed inelastic fraction (14%) is large enough to affect substantially the polarization observed in a previous experiment [10]. If, for example, the inelastic component is polarized oppositely to the elastic, the large asymmetry (0.55 ± 0.13) reported previously [10] can be understood without invoking non-diffractive behaviour in the elastic production.

The authors wish to thank Don Yennie for several illuminating discussions.

References

[1] G. McClellan et al., Phys. Rev. Letters 22 (1969) 374; Phys. Rev. D4 (1971) 2683.
[2] G. McClellan et al., Phys. Rev. Letters 26 (1971) 1593.
[3] H. Alvensleben et al., Phys. Rev. Letters 23 (1969) 1058.
[4] J. Ballam et al., 1971 Intern. Symp. on Electron and photon interactions at high energy, Cornell University.
[5] P. Söding, Phys. Letters 19 (1966) 702.
[6] T. Bauer, Phys. Rev. Letters 25 (1970) 485; J. Pumplin. SLAC - Pub - 730 (1970).
[7] D. Yennie, private communication.
[8] K. Gottfried, Proc. 1971 Intern. Symp. on Electron and phonon interactions at high energies, eds. N. B. Mistry and M. E. Nordberg Jr., Cornell University.
[9] K. Foley et al., Phys. Rev. Letters 11 (1963) 425.
[10] G. McClellan et al., Phys. Rev. Letters 26 (1971) 1597.

* * * * *