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BUBBLE CHAMBER STUDY OF ω-MESON PHOTOPRODUCTION WITH POLARIZED PHOTONS AT 9.3 GeV*

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ABSTRACT

Preliminary results are presented for ω-meson production in the reaction $\gamma p \rightarrow p\,\omega$, based on a 650,000 picture exposure of the LRL-SLAC 82" hydrogen bubble chamber to the monochromatic linearly polarized photon beam at SLAC. We present cross sections, angular distributions, analyze the production mechanism in terms of t channel exchanges and compare these results with our measurements at lower energies. We find that the total ω-production cross section at 9.3 GeV is $1.8 \pm 0.24\,\mu b$. $\langle P_\sigma \rangle = 0.9 \pm 0.2$, implying that natural parity exchange dominates the production mechanism. An overall fit to the data at 2.8, 4.7, and 9.3 GeV shows that the production mechanism is compatible with being made up of a diffractive part like the process $\gamma p \rightarrow p\rho^o$ and an OPE part. Parameterizing the natural exchange part as $d\sigma_N/dt(\omega) \sim B_N e^{A_N t}$ we find $B_N = 9.3 \pm 1.4\,\mu b/GeV^2$ and $A_N = 6.0 \pm 0.6\ GeV^{-2}$.

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Photoproduction of ω mesons by the reaction

$$\gamma p \rightarrow p\omega \tag{1}$$

has now been studied over a wide energy range.[1-5] The total cross section appears to be made up of a contribution depending on photon energy as E_γ^{-2}, suggesting one pion exchange (OPE), and a part roughly constant with energy. The latter has been thought to be due to diffractive dissociation of the photon. In the vector dominance model (VDM), this part would be like the reaction $\gamma p \rightarrow p\rho^o$, viz, $d\sigma/dt\ (\omega) = \gamma_\rho^2/\gamma_\omega^2\ d\sigma/dt\ (\rho)$, where $\gamma_\rho, \gamma_\omega$ are the γ-vector meson coupling constants. Using polarized photons it is possible to separate the contributions of natural and unnatural parity exchange in the t channel.[6] At 2.8 and 4.7 GeV we have shown[3] that the unnatural exchange part is consistent with that expected from OPE. At 9 GeV the OPE contribution is expected to be small; we may then determine better the properties of the natural exchange part, and in particular compare it to ρ^o production at the same energy.

We report results on reaction (1) obtained from 650,000 analyzed pictures of an exposure of the LRL-SLAC 82" hydrogen bubble chamber to the 9.3 GeV linearly polarized backscattered laser beam at SLAC. This corresponds to 138 events/μb in the interval $8 < E_\gamma < 10.3$ GeV. We expect eventually to double these statistics. The photon energy spectrum was an approximately triangular spike with FWHM $\approx$ 600 MeV and 77% average polarization. The spectrum is shown in another contribution to this Conference.[7]

Scanning and measuring procedures were the same as described in our previous report.[3] The measurements of three prong events were fitted to the hypothesis

$$\gamma p \rightarrow p\pi^+\pi^-\pi^o \tag{2}$$

assuming the mean beam energy E_γ to be known to 400 MeV (1-constraint fit) and again leaving E_γ unconstrained (OC fit). Events with at least one such fit were checked for track ionization consistency and were accepted as candidates if no 3C fit to the reactions $\gamma p \rightarrow p\pi^+\pi^-$ or $\gamma p \rightarrow pK^+K^-$ was obtained. The MM^2 distribution for this sample is shown in Fig. 1a where a clear peak corresponding to a single π^o is found.

Figure 1b shows the $\pi^+\pi^-\pi^o$ mass distribution for 1C events. A peak at the ω mass with FWHM of ~ 50 MeV is found. In the following, we use $0.68 < M_{\pi^+\pi^-\pi^o} < 0.88$ GeV as the ω meson region.

To account for losses of ω events due to measurement errors, events corresponding to reaction (1) were generated by the measurement simulation program PHONY, and the above selections were made on these events. It was found that $\sim 16\%$ of the Monte Carlo ω events do not survive our selection criteria, and this correction was applied to our cross sections (we allow for a 50% uncertainty in the correction). Background under the ω was estimated using hand drawn curves as shown by the broken line in Fig. 1b. Because of possible scanning losses, for $|t| < 0.02$ GeV^2 we estimate the number of ω's from a linear exponential extrapolation of $d\sigma/dt$. Using the ω branching ratio to $\pi^+\pi^-\pi^o$ of 0.89,[8] we find $\sigma(\omega) = 1.8 \pm 0.24\,\mu b$ at $E_\gamma = 9.3$ GeV.

The 9 density matrix elements measureable with a linearly polarized photon beam were obtained by the method of moments in the helicity system. These will be treated in more detail later. Here we will use appropriate combinations of these elements to separate out the (noninterfering) contributions from the exchange of natural and unnatural parity sequence objects in the t-channel, of course assuming that t-channel exchanges dominate the reaction. In particular[6]

$$P_\sigma = \frac{\sigma_N - \sigma_U}{\sigma_N + \sigma_U} = 2\rho^1_{1-1} - \rho^1_{00} \qquad (3)$$

measures the natural-unnatural total cross section difference.

We show in Fig. 2 the decay angular distributions in the ω helicity system, together with those found at 2.8 and 4.7 GeV. The normal to the 3π decay plane is the analyzer in the ω CMS, θ_H is the polar angle and Ψ_H is the azimuth taken with respect to the photon polarization plane.[9] As can be seen, an azimuthal dependence $\sim \cos^2 \Psi_H$ builds up with energy, and with it P_σ, indicating the increasing importance of natural parity exchange. At 9.3 GeV we find $P_\sigma = 0.9 \pm 0.2$, averaged over the interval $0.02 < |t| < 0.5$ GeV^2, so that the ω production is $\sim 95\%$ by natural parity exchange. Note that the polar angle distribution does not have a pure $\sin^2 \theta_H$ dependence at any energy.

In Fig. 3 we show the experimental differential cross section $d\sigma/dt\,(\gamma p \to p\omega)$ at 9.3 GeV. The solid line shows that it is well described by a fit to a linear exponential $B\ e^{At}$ with $B = 12.7 \pm 2.4\ \mu b\ GeV^{-2}$ and $A = 7.3 \pm 1.2\ GeV^{-2}$. In Fig. 4 we show the energy dependence of the total ω-production cross section, σ, for our experiments and for other determinations with unpolarized beams.[2,4] We also show the natural and unnatural parts obtained in our experiments using $\sigma_{N,U} = (1 \pm P_\sigma)\sigma/2$.

We now proceed with a more detailed study of the properties of the natural and unnatural components in ω photoproduction, both for the new 9.3 GeV data alone and then including our previously presented data at 2.8 and 4.7 GeV. We fit the differential cross sections to a sum of a natural part,

$$\frac{d\sigma_N}{dt} = B_N\ e^{A_N t} \tag{4a}$$

and an unnatural part

$$\frac{d\sigma_U}{dt} = W\ \frac{d\sigma_{OPE}}{dt}\ (E_\gamma, t). \tag{4b}$$

The first form is a parameterization like the t-dependence of ρ^0 production, and $d\sigma_{OPE}/dt$ is the contribution from OPE. The experimental values of

P_σ (averaged over $0.02 < |t| < 0.5$ GeV^2) were included as additional data points. In the OPE calculation we used the formulation of Wolf[10] (using Benecke-Dürr form factors) and the experimental value for the radiative ω width, $\Gamma(\omega \rightarrow \pi\gamma) = 1.15$ MeV.[8] For the fit at three energies we parameterize B_N by

$$B_N = C\left(1 + \frac{D}{E_\gamma}\right) \qquad (4c)$$

The fit results are given in Table I.

We first remark that the single and multiple energy fits give consistent results. We therefore use the latter values. Note that $W = 0.72 \pm 0.08$ indicates that the absolute OPE calculation can account reasonably well for the unnatural exchange contributions. The curves in Fig. 4 show the natural exchange and OPE parts of σ, as obtained in the fit.

We now compare the natural exchange part of ω production with that of the ρ^0 forward cross section. At the same energy[11] we found the ρ^0 forward cross section to be 83 ± 8 μb/GeV^2 and its slope to be 6.3 ± 0.5 GeV^{-2} (using the phenomenological Söding model). From Table I we see that the t-slopes are within error the same, and the ratio, R, of ρ^0 to ω forward cross sections agrees well with that expected from VDM using the $e^+ - e^-$ storage ring result[12], $R = \gamma_\omega^2/\gamma_\rho^2 = 7.5 \pm 1.5$. We also find the value of D in Eq. (4c) is consistent with the value 4.7 ± 2.1 found for the ρ^0 (making use of our lower energy cross sections.[13]) We conclude that natural exchange ω production as described by VDM, plus a reasonable OPE contribution, can account for all our data.

Finally, we show in Fig. 5 the 9 measureable ω decay density matrix elements, and P_σ, as a function of t, for $E_\gamma = 9.3$ GeV. For ρ^0 photoproduction we have shown[11,13] that the production mechanism is consistent with conserving s-channel helicity at the γ-ρ vertex. Clearly VDM would lead us to expect the same to be true for the diffractive part of ω production. The natural exchange part of the density matrix elements for an unpolarized beam (the only terms contributing to the cross section) are given by[6]

$$\rho^{oN}_{\ell m} = \frac{1}{2}\left[\rho^{o}_{\ell m} - (-1)^{m}\ \rho^{1}_{\ell -m}\right]$$

and these are plotted in Fig. 5 as open circles with dashed errors. Averaged over the interval $0.02 < |t| < 0.5\ \mathrm{GeV}^2$ we find

$$\rho^{oN}_{00} = 0.14 \pm 0.06$$

$$\rho^{oN}_{10} = 0.01 \pm 0.04$$

$$\rho^{oN}_{1-1} = 0.01 \pm 0.06 .$$

ρ^{oN}_{00} measures the intensity of unit helicity flip in the natural exchange part at the γ-ω vertex, and is ~ 2 standard deviations from zero.

If the significance of the deviation in ρ^{oN}_{00} is increased when the full exposure is analyzed, it may still not be necessary to abandon helicity conservation. Another possibility is that natural parity exchange in ω production includes a significant contribution from objects like the A_2. In fact, the observed difference between γp and γn total cross sections was interpreted by Harari[14] as suggesting an $I = 1$ exchange like A_2 must be present, and this exchange could be a significant part of ω production.

In conclusion, we find that the contribution to ω photoproduction from unnatural parity exchange in the t-channel decreases with E_γ like that expected from OPE, becoming a minor part at 9.3 GeV. The natural parity part remains nearly constant with energy and the E_γ and t dependence is compatible with that of ρ^{o} photoproduction.

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9. We analyze the ω decay in the helicity frame, where the z axis is the direction of the ω in the overall (γp) CMS. The y axis is the normal to the production plane, defined by the cross product $\hat{k} \times \hat{\omega}$ of the directions of the photon and the ω meson. The angle Φ between the electric vector of the photon, $\hat{\epsilon}$, and the production plane in the total c.m. system is defined by $\cos \Phi = \hat{\epsilon} \cdot (\hat{y} \times \hat{k})$, $\sin \Phi = \hat{y} \cdot \hat{\epsilon}$. The decay angles θ, ϕ are the polar and azimuthal angles of the normal $\hat{n} \propto \vec{\pi}^+ \times \vec{\pi}^-$ to the ω decay plane in the ω rest system:
$\cos \theta = \hat{n} \cdot \hat{z}$, $\cos \phi = \hat{y} \cdot (\hat{z} \times \hat{n}) / |\hat{z} \times \hat{n}|$, $\sin \phi = -\hat{x} \cdot (\hat{z} \times \hat{n}) / |\hat{z} \times \hat{n}|$
The x axis is given by $\hat{x} = \hat{y} \times \hat{z}$; $\Psi = \phi - \Phi$.

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TABLE I

Results of single and multiple energy fits to the parameterization of Eqs. (4). The values given all refer to ω (and ρ) production at $E_\gamma = 9.3$ GeV.

	Single Energy Fit	3 Energy Fit
σ_N (μb)	1.7 ± 0.3	1.6 ± 0.2
σ_U (μb)	0.1 ± 0.3	0.26 ± 0.03
B_N (μb GeV^{-2})	12.0 ± 2.7	9.3 ± 1.4
A_N (GeV^{-2})	7.2 ± 1.3	6.0 ± 0.6
W	0.24 ± 0.43	0.72 ± 0.08
D (GeV^{-1})	—	3.0 ± 1.9
C (μb GeV^{-2})	—	7.0 ± 1.9
$R = \frac{d\sigma_\rho/dt\,(t=0)}{B_N}$	7.0 ± 1.7	9.0 ± 1.6
χ^2/D. F.	0.5/4	22.7/21

FIGURE CAPTIONS

1. (a) Missing mass squared for 3-prong events not fitting $\gamma p \to p\pi^+\pi^-$ or $\gamma p \to pK^+K^-$ and consistent with $\gamma p \to p\pi^+\pi^-\pi^0$, using the mean beam energy. (b) Mass of $\pi^+\pi^-\pi^0$ for 1C fit events in (a). Broken line is estimated background.

2. Decay angular distributions and P_σ for ω events (selected from the interval $0.74 < M_{\pi^+\pi^-\pi^0} < 0.84$ GeV without background subtraction) at 2.8, 4.7, and 9.3 GeV in the helicity system. The decay angular distributions are for $0.02 < |t| < 0.3$ GeV^2, P_σ is for $0.02 < |t| < 0.5$ GeV^2. The curves give the decay distributions resulting from the experimental decay matrix elements.

3. Differential cross section for the reaction $\gamma p \to p\omega$ at 9.3 GeV. The solid line is a linear exponential fit to the data points.

4. Total cross sections for the reaction $\gamma p \to p\omega$ as a function of photon energy. The points labeled "DESY-HBC" and "SLAC Annihilation Beam" are from Ref. 2 and Ref. 4, respectively. Also shown are the natural and unnatural parts found from the polarized beam exposures. The full and dashed curves show the diffractive and OPE parts respectively as given by the overall fit.

5. The nine measureable density matrix elements of the ω, and P_σ, as function of t for $\gamma p \to p\omega$ at 9.3 GeV. The symbol ϕ on the superscript zero elements shows the natural parity exchange contributions.

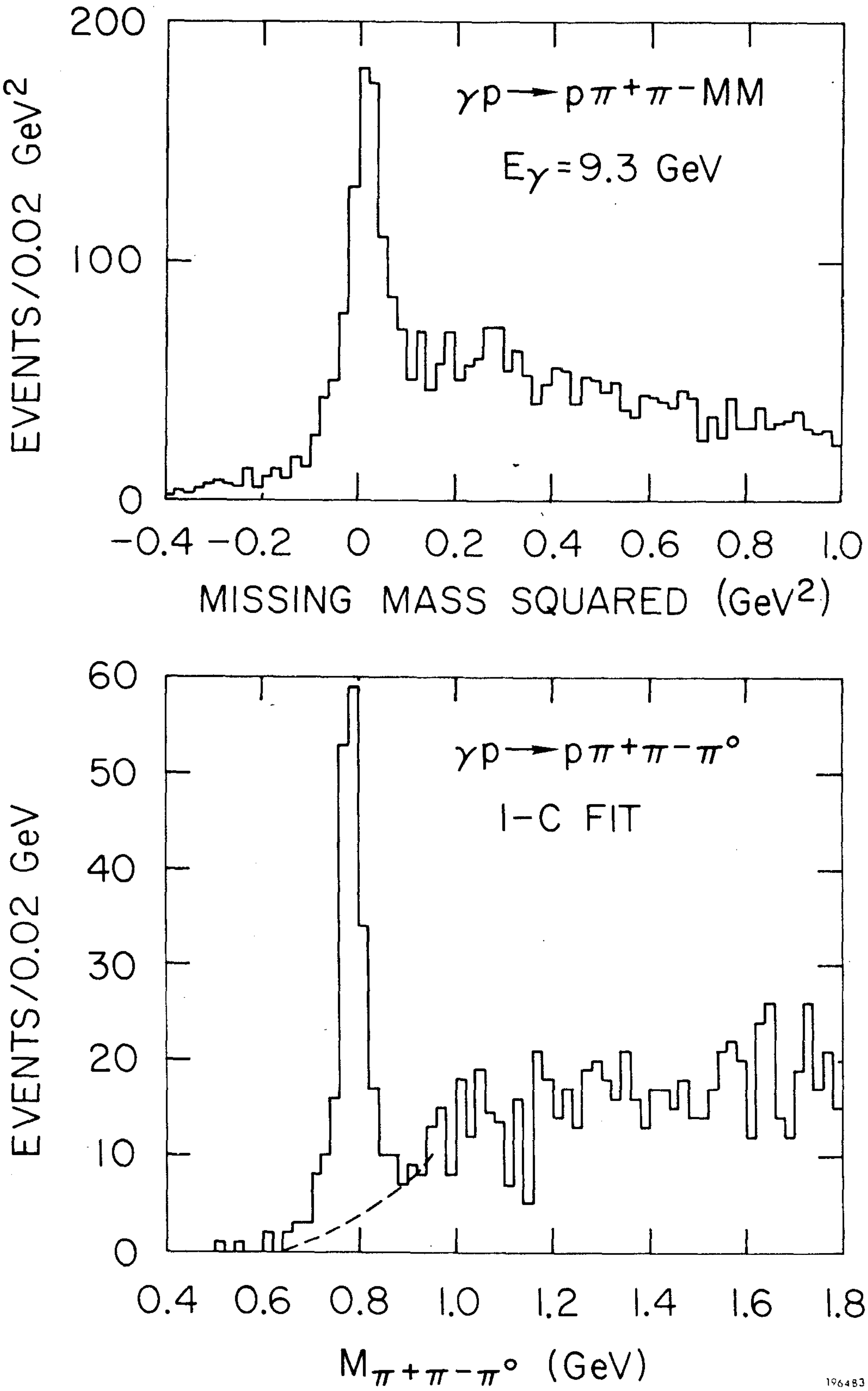

200
100
0
EVENTS/0.02 GeV2
γp → pπ+π−MM
Eγ = 9.3 GeV
−0.4 −0.2 0 0.2 0.4 0.6 0.8 1.0
MISSING MASS SQUARED (GeV2)
60
50
40
30
20
10
0
EVENTS/0.02 GeV
γp → pπ+π−π°
1−C FIT
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8
Mπ+π−π° (GeV)
196483

Fig. 1

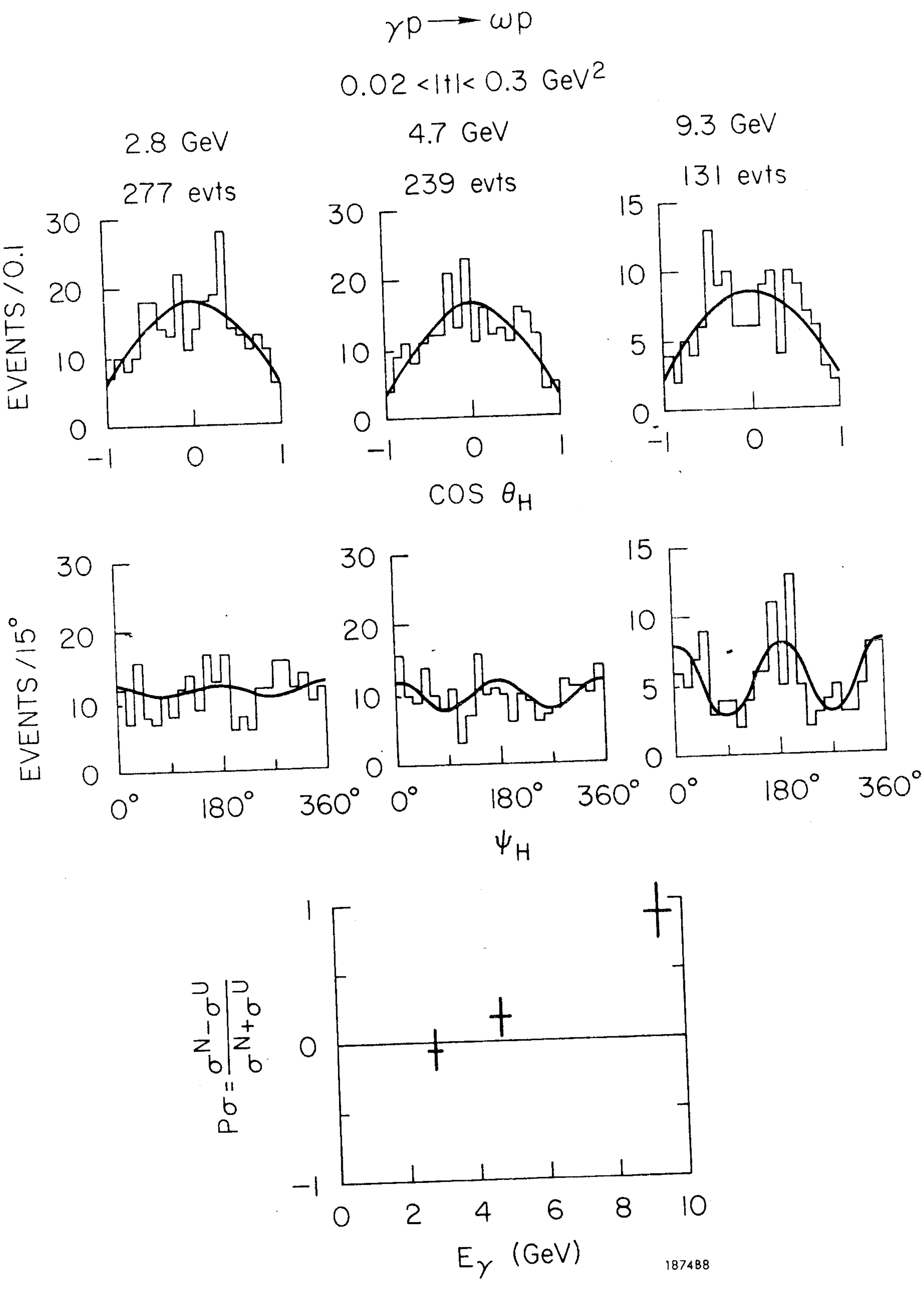
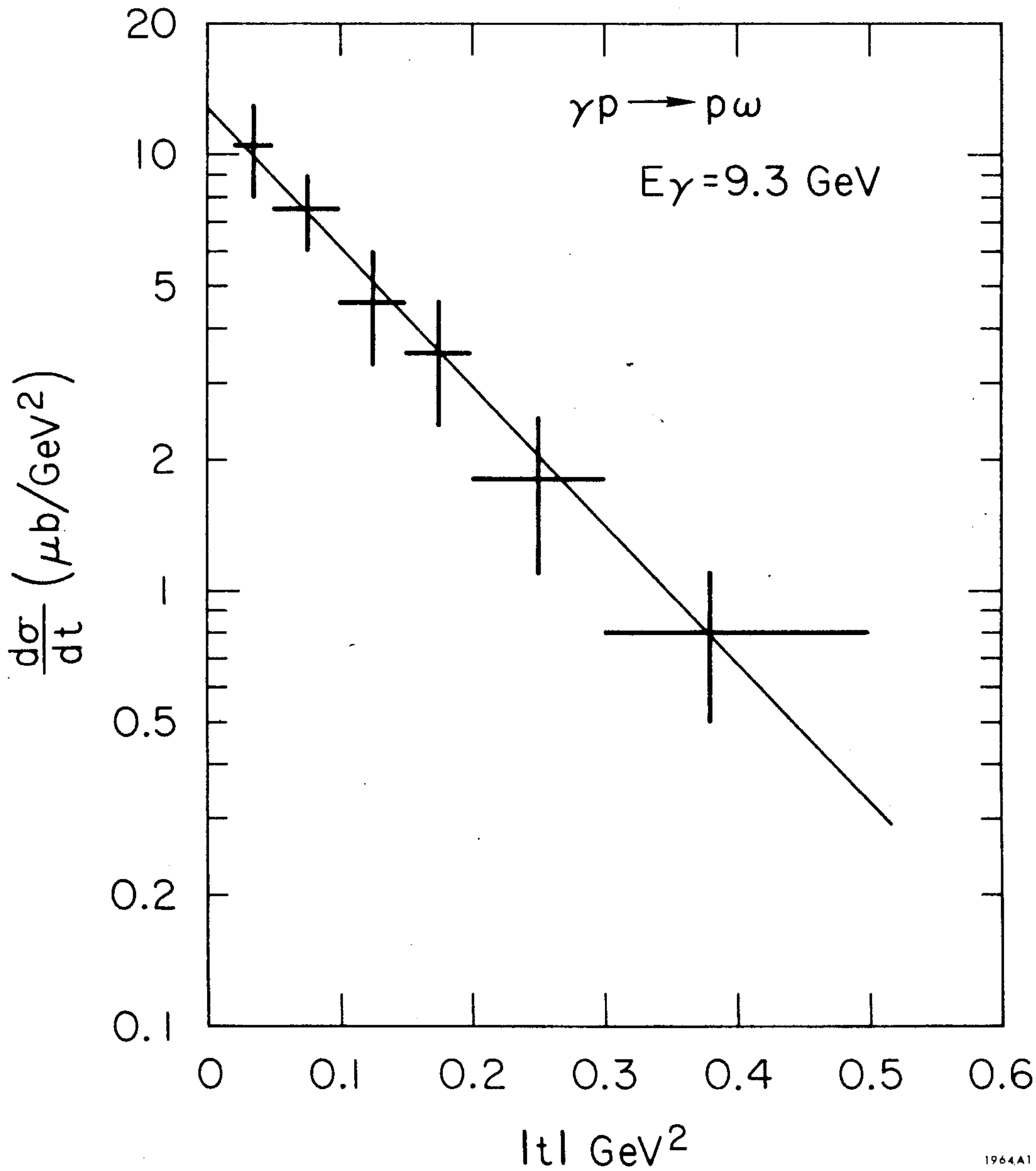
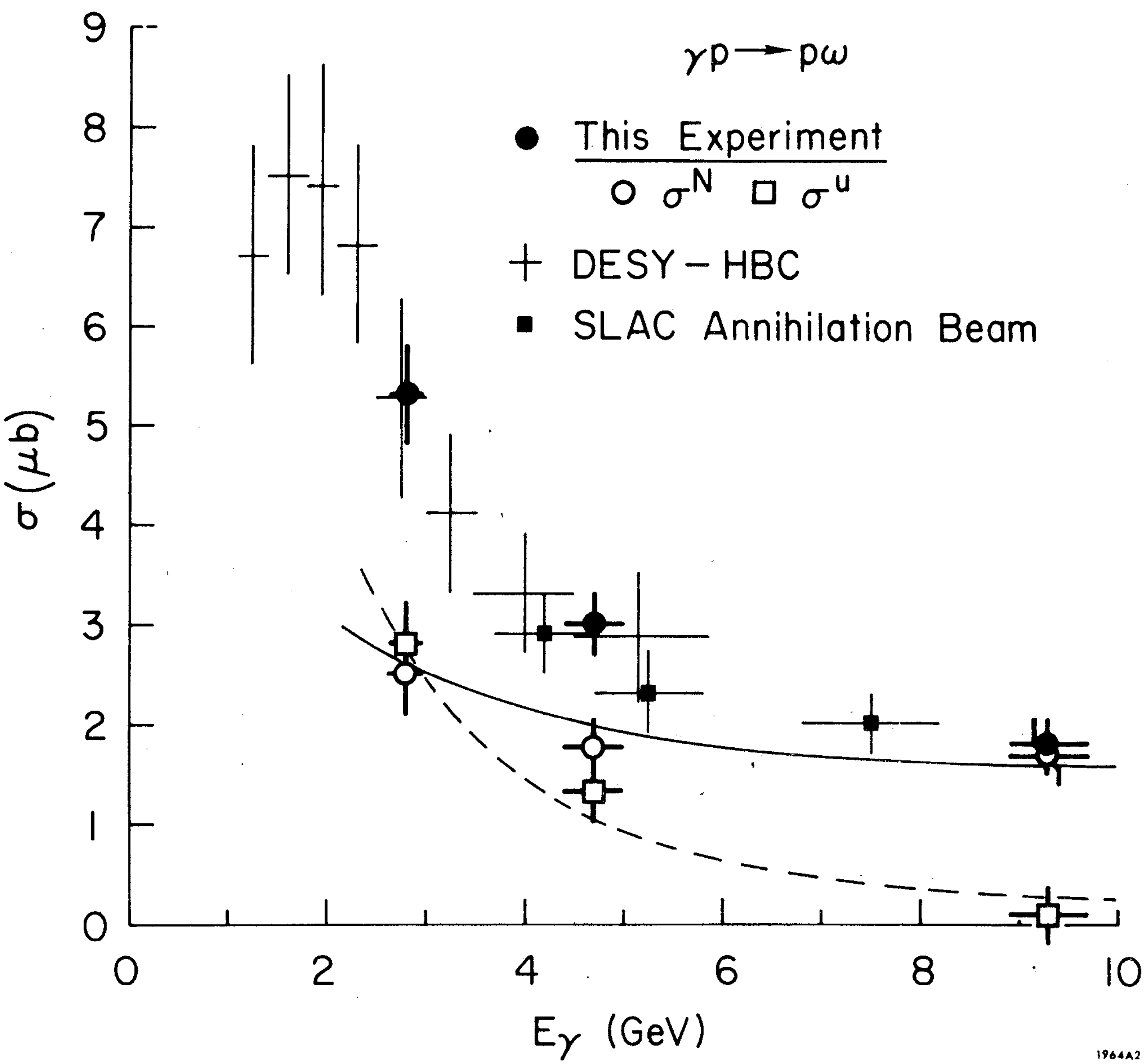

γp → ωp
0.02 < |t| < 0.3 GeV²
2.8 GeV
277 evts
4.7 GeV
239 evts
9.3 GeV
131 evts
EVENTS / 0.1
COS θ_H
EVENTS / 15°
0° 180° 360°
ψ_H
Pσ = (σ^N − σ^U)/(σ^N + σ^U)
E_γ (GeV)
187488

Fig. 2



γp → pω
Eγ=9.3 GeV
dσ/dt (μb/GeV²)
|t| GeV²
20
10
5
2
1
0.5
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
1964A1

Fig. 3



γp → pω
This Experiment
σ^N σ^u
DESY-HBC
SLAC Annihilation Beam
σ (μb)
E_γ (GeV)
0
1
2
3
4
5
6
7
8
9
0
2
4
6
8
10
1964A2

Fig. 4

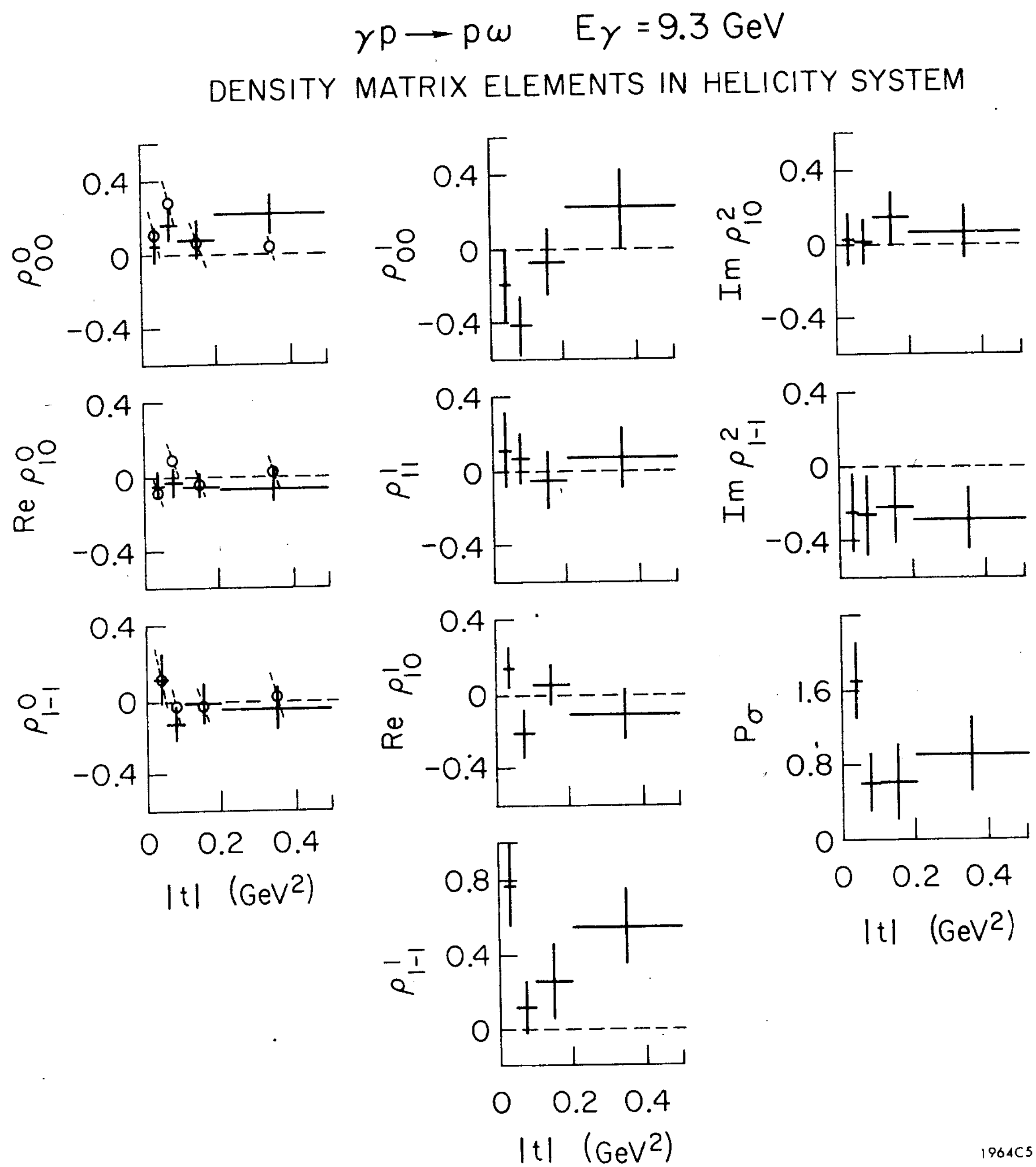

γp → pω   Eγ = 9.3 GeV
DENSITY MATRIX ELEMENTS IN HELICITY SYSTEM
ρ⁰₀₀
Re ρ⁰₁₀
ρ⁰₁₋₁
ρ¹₀₀
ρ¹₁₁
Re ρ¹₁₀
ρ¹₁₋₁
Im ρ²₁₀
Im ρ²₁₋₁
Pσ
0.4
0
-0.4
0.8
1.6
0 0.2 0.4
|t| (GeV²)
1964C5

Fig. 5