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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 and decay 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 $2.0 \pm 0.25\ \mu b$. P_σ is 0.97 ± 0.2, implying that natural parity exchange dominates the production mechanism. Parameterizing the natural exchange part as $d\sigma_N/dt\,(\omega) \sim B_N e^{A_N t}$ we find $B_N = 17.3 \pm 3.5\ \mu b/GeV^2$ and $A_N = 9.0 \pm 1.6\ GeV^{-2}$. 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.

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Photoproduction of ω mesons by the reaction

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

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 the properties of the natural exchange part, and in particular compare it to ρ^o production at the same energy.

We report preliminary results on reaction (1) obtained from 650,000 analyzed pictures of an exposure of the SLAC-LRL 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] Three prong event measurements were "fitted" to the zero constraint hypothesis

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

checked for track ionization consistency, and accepted as candidates if no 3C fit to the reaction $\gamma p \to p\pi^+\pi^-$ was obtained. By assuming E_γ to be the mean beam energy, a missing mass (MM) was also calculated. The MM^2 distribution is shown in Fig. 1(a) where a clear peak corresponding to a single π^0 is found. The final selection for reaction (2) was to require $MM^2 < 0.1\ GeV^2$. Figure 1(b) shows the $\pi^+\pi^-\pi^0$ mass distribution for these events. A peak at the ω mass with FWHM of 60 MeV is found. In the following, events with $0.68 < M_{\pi^+\pi^-\pi^0} < 0.92$ GeV were used.

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 same selections were made on these events. It was found that 26% of the Monte Carlo ω events do not survive the cuts, and this correction was applied to our cross sections (we allow for a 30% uncertainty in the correction). Background under the ω was estimated using hand drawn curves as shown by the broken line in Fig. 1(b). 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 $\pi^+\pi^-\pi^0$ of 0.89,[8] we find $\sigma(\omega) = 2.0 \pm 0.25\ \mu b$ 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. Appropriate combinations of these elements can be used 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]

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

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 $P_\sigma = 0.97 \pm 0.21$, averaged over the interval $0.02 < |t| < 0.5$ GeV^2, so that the ω production is mostly 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. A fit of this data to a linear exponential $B\,e^{At}$ gives $B = 17.3 \pm 3.5$ μb GeV^{-2} and $A = 9.0 \pm 1.6$ GeV^{-2}. At the same energy[10] we find the ρ^0 forward cross section to be 81 ± 5 μb/GeV^2 and the slope 6.5 ± 0.3 GeV^{-2} (using the Söding model). Assuming that the OPE contribution to ω production is negligible at 9.3 GeV, we find the ratio, R, of ρ^0 to ω forward cross sections at 9.3 GeV is $R = 4.7 \pm 1.0$, compared to that expected from VDM using the $e^+ - e^-$ storage ring results,[11] $R = \gamma_\omega^2/\gamma_\rho^2 = 7.5 \pm 1.5$. Within 1.5 standard deviations there is agreement in both slope and magnitude with the expectations from VDM, so that at this stage of the experiment we do not attribute significance to the discrepancy.[12]

We now extend the VDM test to include the data obtained at 2.8 and 4.7 GeV.[3] 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 have fit the differential cross sections found at our three energies to the sum of

$$\frac{d\sigma_N}{dt} = D e^{At} E_\gamma^{-n}$$

and

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

The first form is a parameterization of the E_γ and 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[13] (using Benecke-Dürr form factors) and the experimental value for the radiative ω width, $\Gamma(\omega \rightarrow \pi\gamma) = 1.15$ MeV.[8] We find $W = 0.72 \pm 0.08$ indicating that the OPE calculation can account reasonably well for the unnatural exchange contributions. We also find $A = 6.4 \pm 0.6\ GeV^{-2}$ and $n = 0.3 \pm 0.2$, in good agreement with our measurements of ρ^0 photoproduction,[10, 14] and a value for D which yields a ρ-ω forward ratio $R = 7 \pm 1$. The χ^2 for 21 degrees of freedom was 26.4. We conclude that diffractive ω production as described by VDM, plus a reasonable OPE contribution, can account for all our data, and the steeper slope found at 9.3 GeV is compatible with being a statistical fluctuation. The curves in Figs. 3 and 4 show the diffraction and OPE contributions to σ obtained in the fit.

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[10, 14] 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 $0.02 < |t| < 0.5$ GeV^2 we find

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

$$\rho^{oN}_{10} = 0.03 \pm 0.04$$

$$\rho^{oN}_{1-1} = -0.02 \pm 0.06 \quad ;$$

ρ^{oN}_{00} measures the intensity of unit helicity flip in the natural exchange part at the γ-ω vertex, and is 2.3 standard deviations from zero.

This apparent deviation from helicity conservation may be connected with the result that σ_U at 9.3 GeV is slightly lower than expected from the OPE calculation when the lower energy points are included in the fit.[15] If the significance of the deviation in ρ^{oN}_{00} is increased when the full exposure is analyzed, it may indicate 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[16] 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 contributions to ω photoproduction from unnatural parity exchange in the t-channel decrease 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 dependence is compatible with that of ρ^{o} photoproduction.

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3. J. Ballam et al., Phys. Rev. Letters 24, 1364 (1970), 26, 155 (1971E).

4. Y. Eisenberg et al., Phys. Letters 34B, 439 (1971).

5. M. Davier et al., Phys. Letters 28B, 619 (1969).

6. K. Schilling et al., Nucl. Phys. B15, 379 (1970), R. L. Thews, Phys. Rev. 175, 1749 (1968).

7. J. Ballam et al., "A study of the inclusive reaction $\gamma p \rightarrow \pi^- +$ anything with polarized photons at 2.8, 4.7 and 9.3 GeV," submitted to this Conference.

8. Particle Data Group, Phys. Letters 33B, 1 (1970).

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, ϵ, 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 $\hat{n} = \pi^+ \times \pi^-$ to the ω decay plane in the ω rest system:

$$\cos \theta = \hat{n} \cdot \hat{z} \qquad \cos \phi = \hat{y} \cdot (\hat{z} \times \hat{n}) / |\hat{z} \times \hat{n}| \qquad \sin \phi = -\hat{x} \cdot (\hat{z} \times \hat{n}) / |\hat{z} \times \hat{n}|$$

The x axis is given by $\hat{x} = \hat{y} \times \hat{z}$; $\Psi = \phi - \Phi$.

10. J. Ballam et al., "A study of the channel $\gamma p \rightarrow p \pi^+ \pi^-$ using a linearly polarized photon beam of energy 9.3 GeV," Report submitted to this Conference.

11. J. E. Augustin et al., International Symposium on Electron and Photon Interactions at High Energies, Liverpool (Sept. 1969), and Phys. Letters 28B, 508, 513, 517 (1969).

12. We have checked that the difference in slope cannot be accounted for by the ω event selection criteria or by the background subtractions. From the PHONY studies we find an insignificant t-dependence of losses due to our cuts. If no background subtraction is made, the fitted slope decreases only to 8.4 ± 0.7 GeV^{-2}, so that wrong background corrections are unlikely to have produced the large slope.

13. G. Wolf, Phys. Rev. 182, 1538 (1969).

14. J. Ballam et al., Phys. Rev. Letters 24, 960 (1970); J. Ballam et al., "Bubble Chamber study of photoproduction by 2.8 and 4.7 GeV polarized photons," submitted to this Conference.

15. For a fuller test of statistical significance, we have evaluated the likelihood function of the decay angular distribution for events in the ω mass region assuming a helicity conserving ω plus (a) 10% OPE contribution (helicity conserving in the t-channel) and 6% isotropic background as suggested by the overall fit and the $\pi^+\pi^-\pi^o$ mass distribution, respectively; (b) 10% OPE plus 6% background with a $\cos^2\theta_H$ distribution, and (c) the worst case, 20% OPE (upper limit corresponding to one standard deviation in P_σ) plus 6% $\cos^2\theta_H$ background. We find the probabilities are 3.5% for (a), 14% for (b) and 34% for (c), indicating that the present analysis is compatible with having helicity conservation for the diffractive part of the ω.

16. H. Harari, International Symposium on Electron and Photon Interactions at High Energies, Liverpool (Sept. 1969), p. 107.

FIGURE CAPTIONS

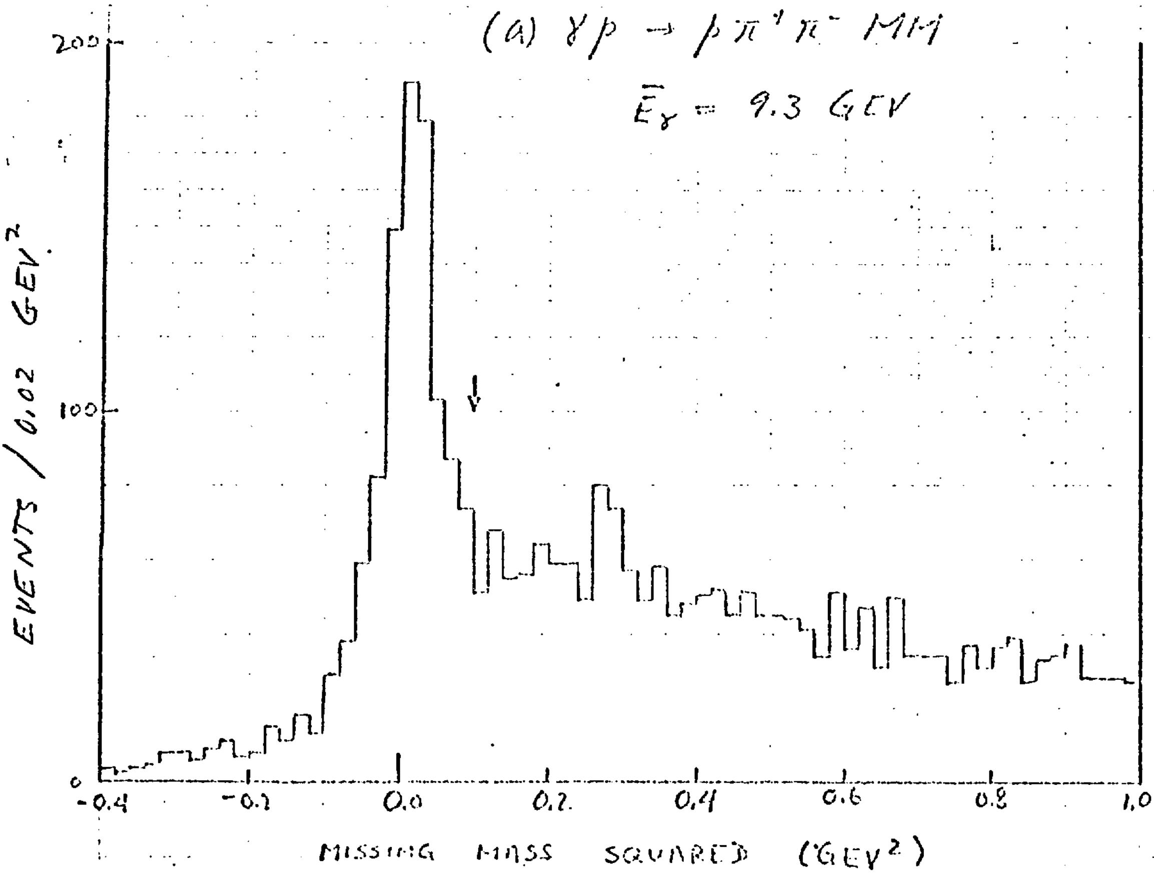
1. (a) Missing mass squared for 3-prong events not fitting $\gamma p \to p\pi^+\pi^-$ and consistent with $\gamma p \to p\pi^+\pi^-\pi^0$ using the mean beam energy. The arrow indicates the upper limits used to select events. (b) Mass of $\pi^+\pi^-\pi^0$ for events in (a) with missing mass squared $< 0.1\ GeV^2$. Broken line is estimated background.

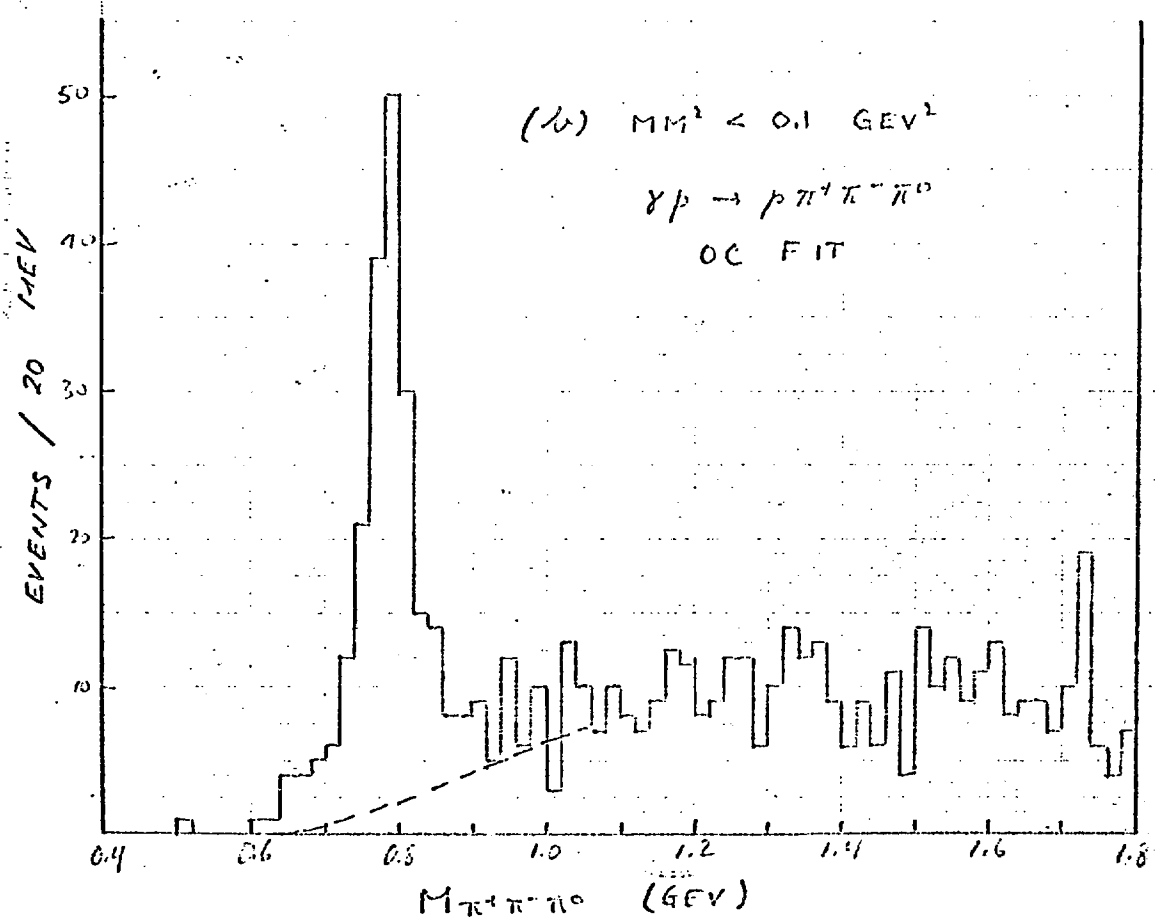
2. Decay angular distributions and P_σ for ω events (selected from the interval $0.74 < M_{\pi^+\pi^-\pi^0} < 0.84$ GeV without background subtraction) at 2.8, 4.7, and 9.3 GeV in the helicity system. The curves give the decay distributions resulting from the experimental decay matrix elements.

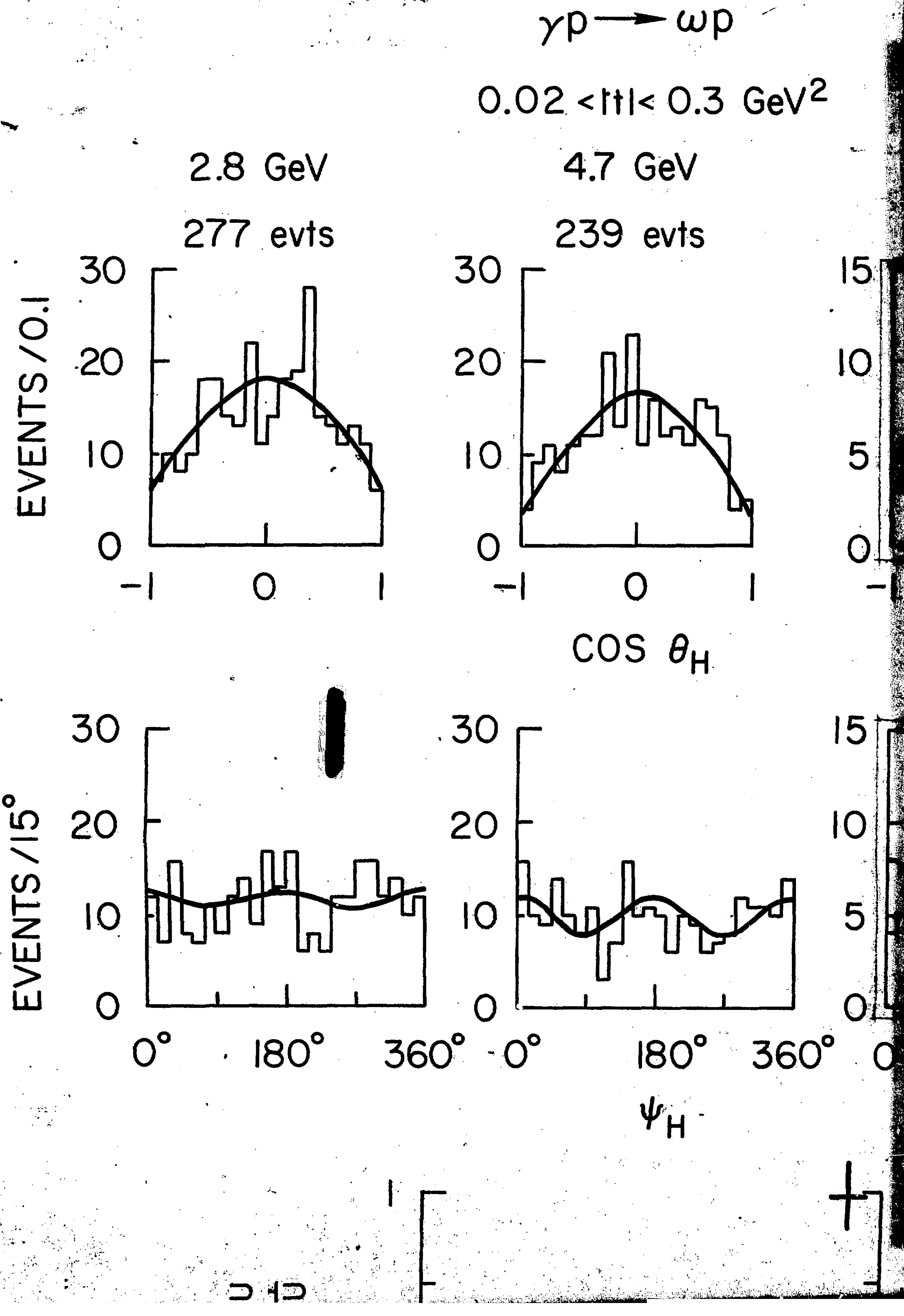
3. Differential cross section for the reaction $\gamma p \to p\omega$ at 9.3 GeV. The solid line is the fit to the total distribution, while the broken lines show the diffraction (dot-dash) and diffraction plus OPE (dashed) parts as determined from the fits described in the text.

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," respectively, are from Ref. 2 and Ref. 4, respectively. Also shown are the natural and unnatural parts found from the polarized beam exposures. The curves show the diffractive and OPE parts as given by the overall fit.

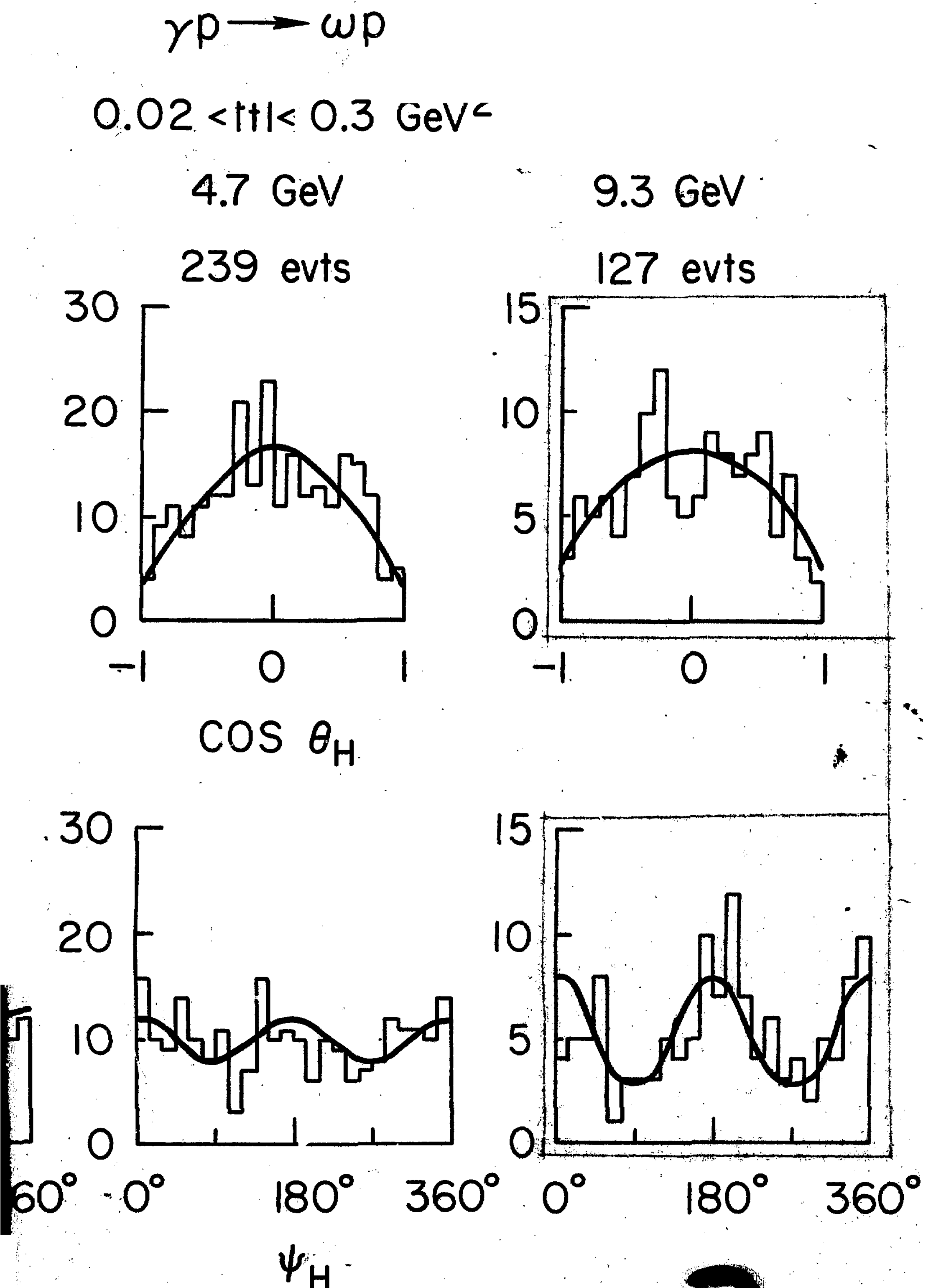
5. The nine measureable density matrix elements of the ω, and P_σ, as function of t for $\gamma p \to p\omega$ at 9.3 GeV. The symbol o on the superscript zero elements shows the natural parity exchange contributions.


(a) $\gamma p \to p \pi^+ \pi^-$ MM
$\bar{E}_\gamma = 9.3$ GEV
EVENTS / 0.02 GEV^2
200
100
0
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
MISSING MASS SQUARED (GEV^2)

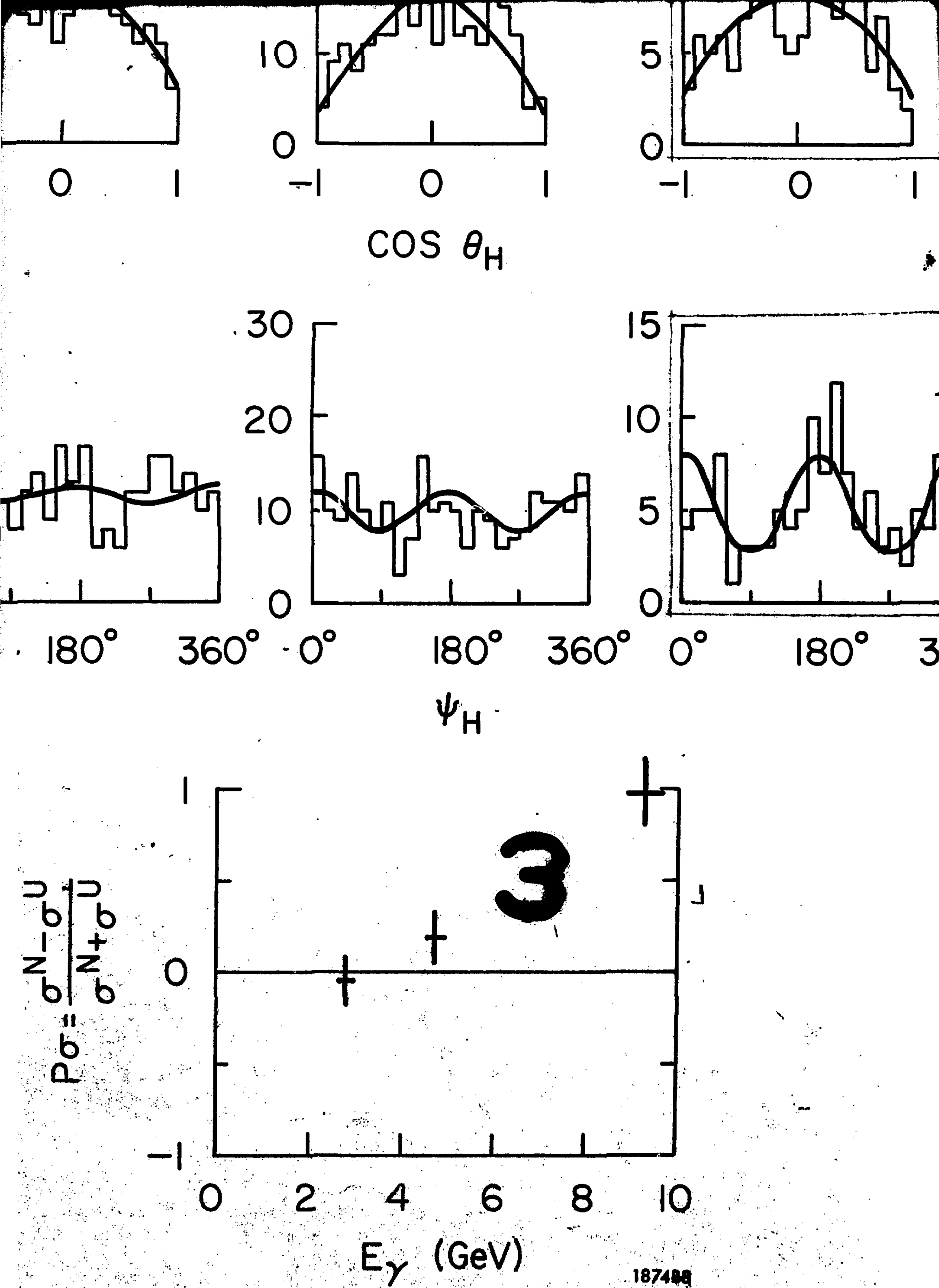

(b) MM^2 < 0.1 GEV^2
$\gamma p \to p \pi^+ \pi^- \pi^0$
0C FIT
EVENTS / 20 MEV
50
40
30
20
10
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
$M_{\pi^+\pi^-\pi^0}$ (GEV)



γp → ωp
0.02 < |t| < 0.3 GeV²
2.8 GeV
277 evts
4.7 GeV
239 evts
EVENTS / 0.1
COS θ_H
EVENTS / 15°
ψ_H
0°
180°
360°


γp → ωp
0.02 < |t| < 0.3 GeV²
4.7 GeV
9.3 GeV
239 evts
127 evts
30
20
10
0
15
10
5
0
-1
0
1
COS θ_H
0°
180°
360°
ψ_H

2


10
0
5
-1
1
COS θ_H
30
20
15
180°
360°
0°
ψ_H
$P_\sigma = \frac{\sigma_N - \sigma_U}{\sigma_N + \sigma_U}$
2
4
6
8
E_γ (GeV)
187488

3

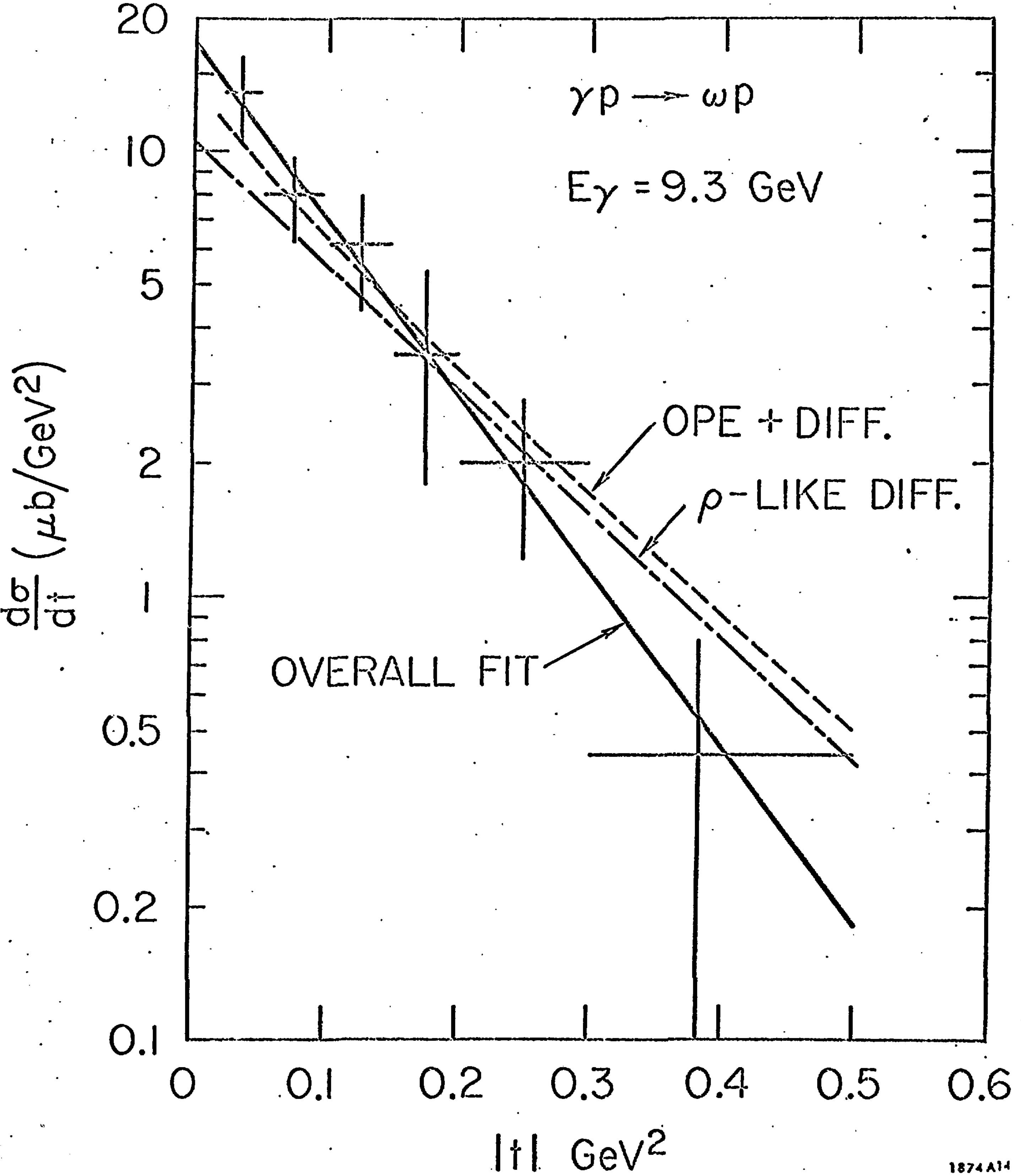
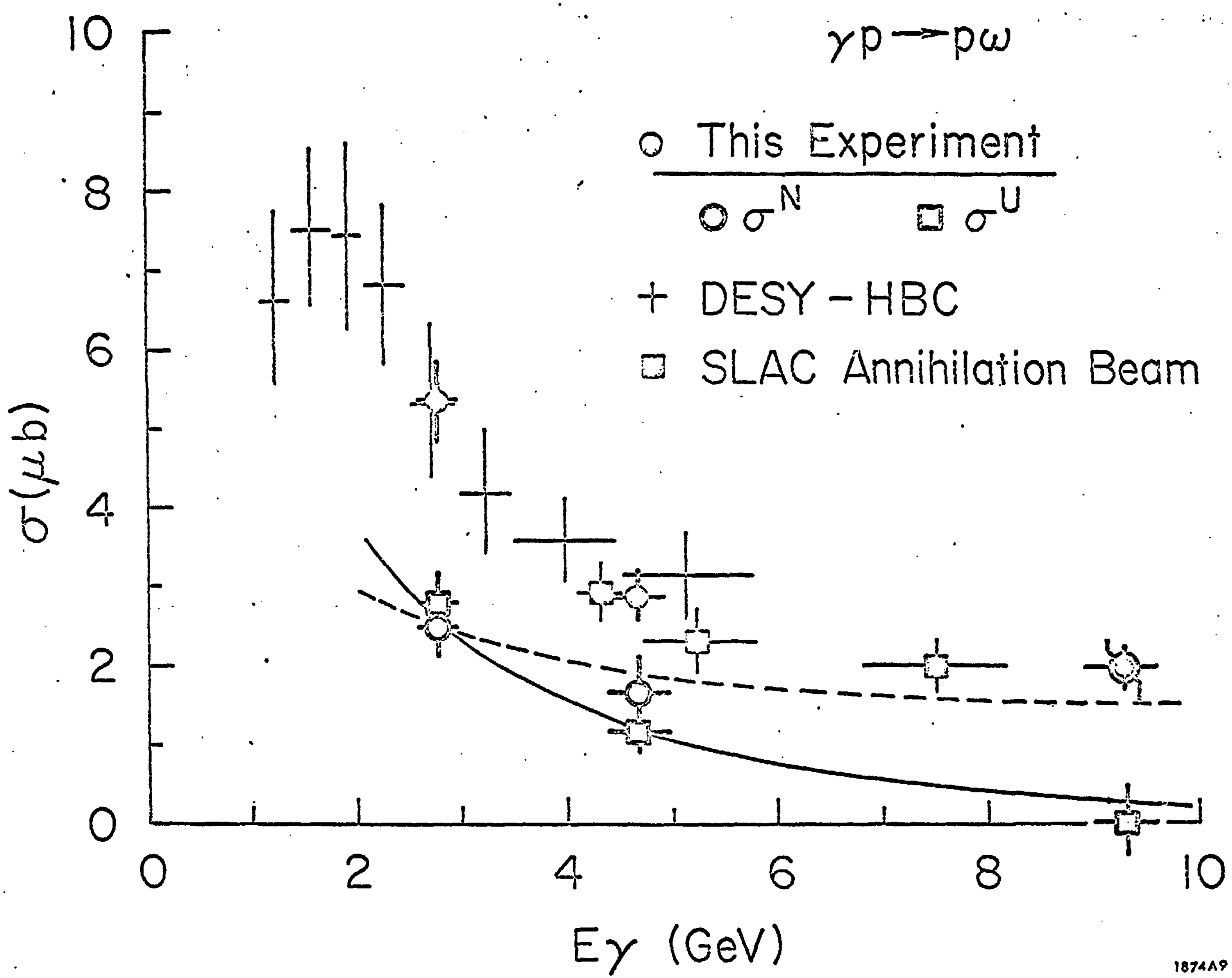
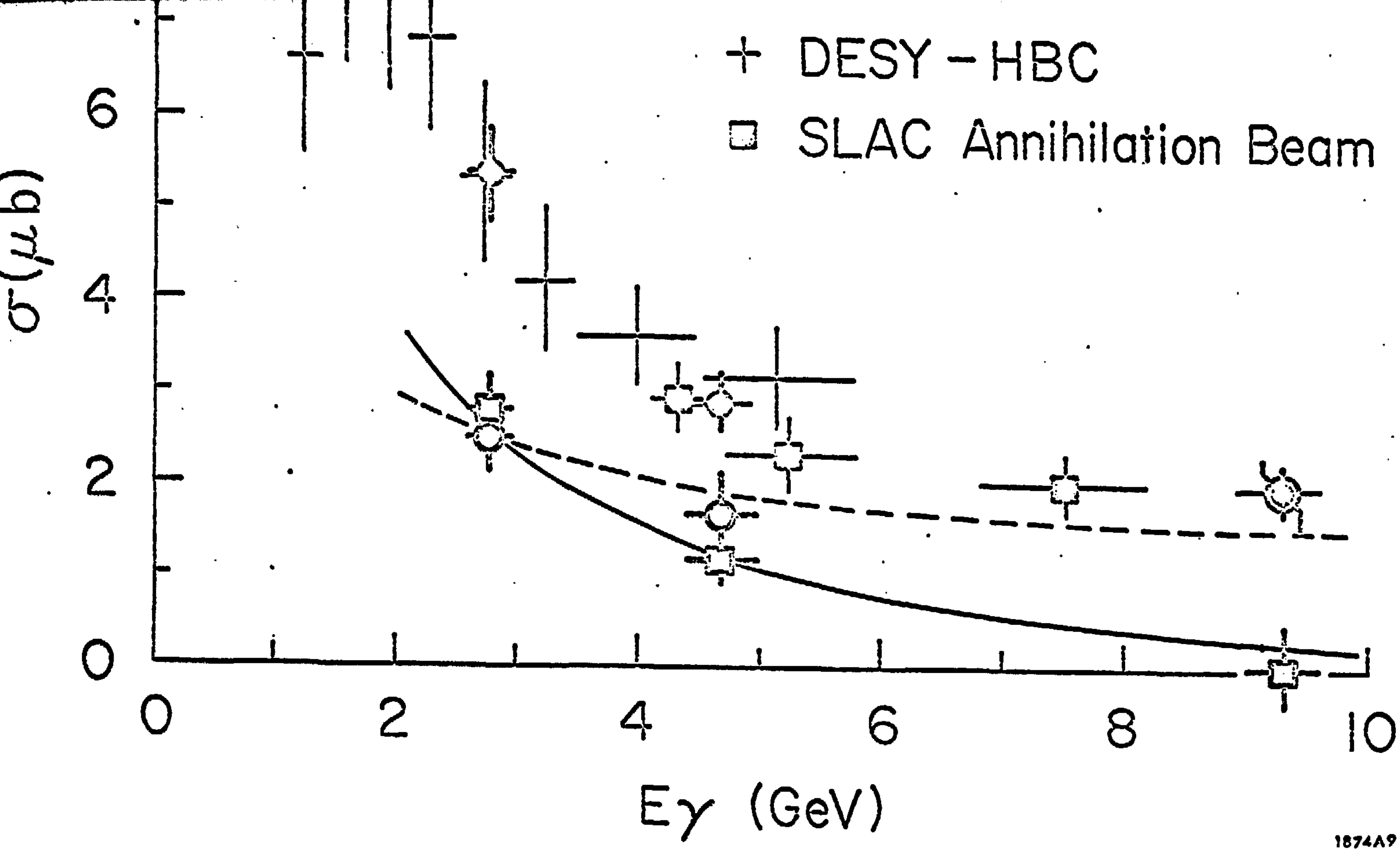

γp → ωp
Eγ = 9.3 GeV
OPE + DIFF.
ρ-LIKE DIFF.
OVERALL FIT
dσ/dt (μb/GeV²)
|t| GeV²
20
10
5
2
1
0.5
0.2
0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
1874A14

Fig. 3



γp → pω
This Experiment
σ^N
σ^U
DESY - HBC
SLAC Annihilation Beam
σ(μb)
Eγ (GeV)
0
2
4
6
8
10
1874A9

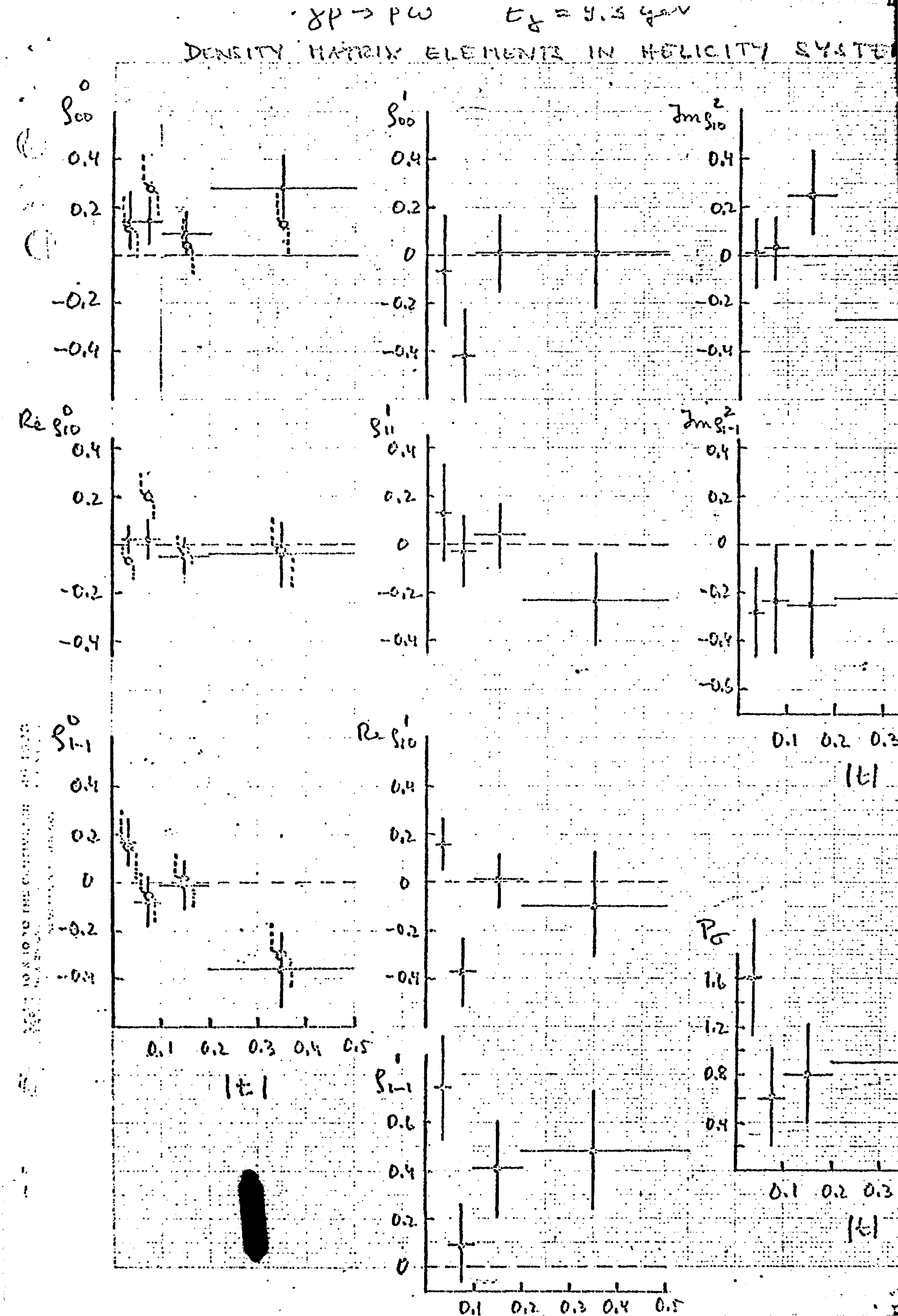
Fig. 4



DESY-HBC
SLAC Annihilation Beam
σ(μb)
0
2
4
6
0
2
4
6
8
10
Eγ (GeV)
1874A9

Fig. 4

92


γp → pω   E_γ = 9.3 GeV
DENSITY MATRIX ELEMENTS IN HELICITY SYSTEM
ρ⁰₀₀
ρ¹₀₀
Im ρ²₁₀
Re ρ⁰₁₀
ρ¹₁₁
Im ρ²₁₋₁
ρ⁰₁₋₁
Re ρ¹₁₀
ρ¹₁₋₁
P_σ
0.1 0.2 0.3 0.4 0.5
|t|

γp → pω E_γ = 9.3 GeV

DENSITY MATRIX ELEMENTS IN HELICITY SYSTEM

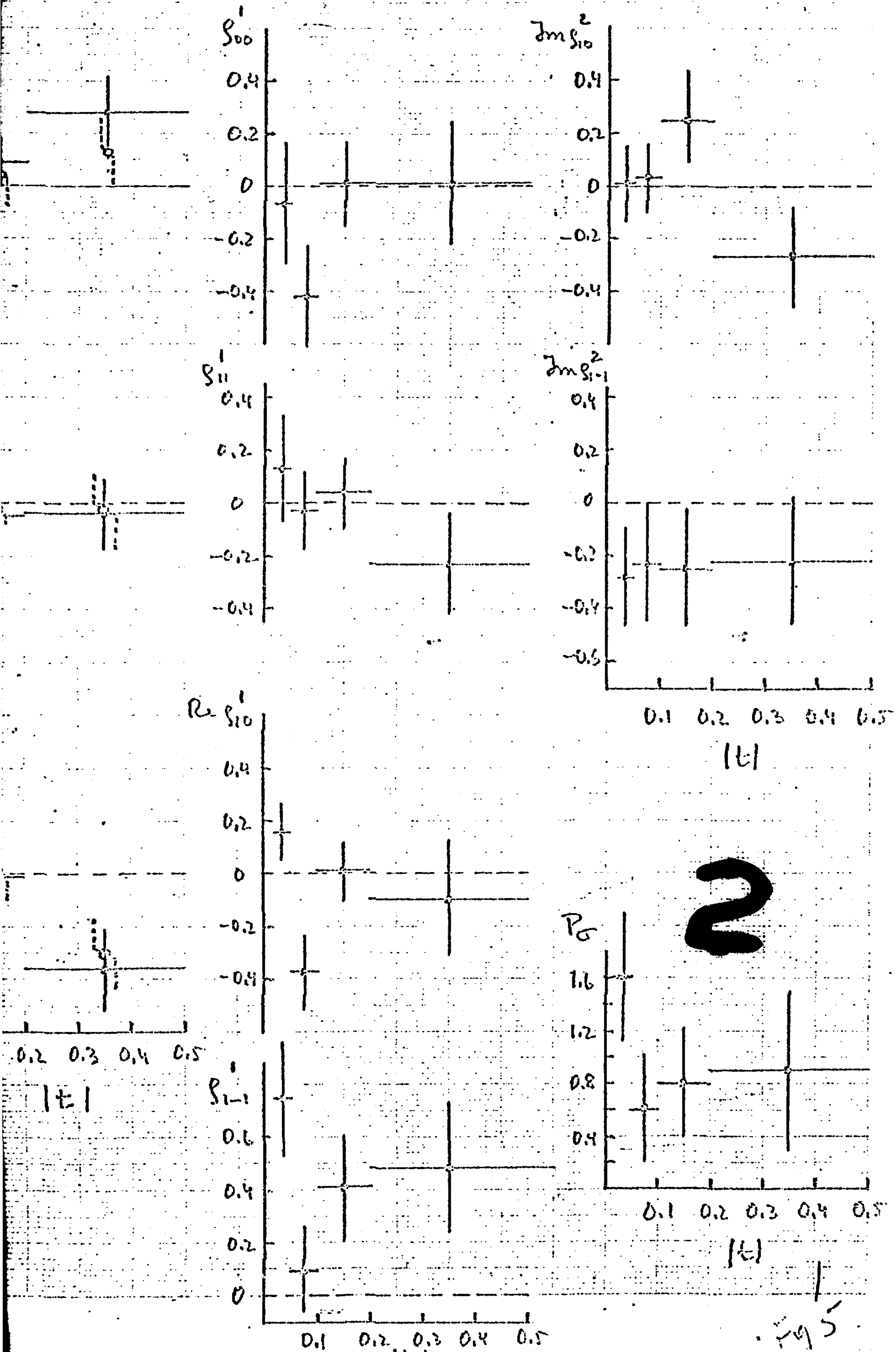


Fig 5