Experimental Review on ω Production

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for the

CLAS Collaboration

NSTAR-2004
Grenoble, France
25 March 2004

Idaho State University

Partial widths for photon and hadronic couplings to the $I = \frac{1}{2}$ baryon resonances in the Isgur-Karl model. The total hadronic width, summed over all identified channels, is also given. The units are in MeV.

N.B. N(1870) = PDG: N(1900)

Mass	J^π	γp	πN	$\pi\Delta$	ρN	ωN	Total
N(1490)	$1/2^-$	1.3	28.	2.9	40.	0.	98.
N(1655)	$1/2^-$	0.72	76.	67.	102.	1.4	262.
N(1535)	$1/2^-$	0.58	85.	52.	27.	0.	164.
N(1745)	$3/2^-$	0.009	13.	317.	26.	2.9	360.
N(1670)	$5/2^-$	0.013	30.	86.	5.3	0.	130.
N(1405)	$1/2^+$	0.026	46.	5.8	0.1	0.	52.
N(1705)	$1/2^+$	0.23	45.	13.	36.	0.8	108.
N(1890)	$1/2^+$	0.057	19.	12.	22.	37.	96.
N(2055)	$1/2^+$	0.009	1.4	3.2	1.7	32.	39.
N(1710)	$1/2^+$	1.0	42.	4.4	156.	32.	242.
N(1870)	$3/2^+$	0.027	10.	19.	2.3	98.	149.
N(1955)	$3/2^+$	0.021	1.2	88.	56.	90.	236.
N(1980)	$3/2^+$	0.031	1.2	96.	71.	55.	223.
N(2060)	$3/2^+$	0.0001	0.3	31.	15.	98.	145.
N(1715)	$5/2^+$	0.29	50.	4.4	20.	1.4	77.
N(1955)	$5/2^+$	0.24	0.2	64.	67.	184.	324.
N(2025)	$5/2^+$	0.001	1.7	67.	66.	180.	316.
N(1955)	$7/2^+$	0.006	9.6	36.	18.	53.	126.

Table 1: **SU(6) ⊗ O(3) supermultiplet assignments from the QCD-improved model of Cutkosky for the measured and *missing* baryon resonances. The boxed supermultiplets are fully consistent with the diquark model. [ω is an ISOSPIN FILTER (I=0)].**

[a]Oh, Titov, & Lee * [b]Penner & Mosel * [c]Zhao, Li, & Bennhold * [d]Titov & Lee

N.B. P13(1870) = PDG: P13(1900) **No Star means *missing resonance***

N^*	Status	SU(6) ⊗ O(3)	Parity	Δ^*	Status	SU(6) ⊗ O(3)
P11(938)	****	(56,0$^+$)	+	P33(1232)	****	(56,0$^+$)
S11(1535)[c]	****	(70,1$^-$)				
S11(1650)	****	(70,1$^-$)		S31(1620)	****	(70,1$^-$)
D13(1520)[c,d]	****	(70,1$^-$)	−	D33(1700)	****	(70,1$^-$)
D13(1700)	***	(70,1$^-$)				
D15(1675)	****	(70,1$^-$)				
P11(1520)	****	(56,0$^+$)		P31(1875)	****	(56,2$^+$)
P11(1710)[b]	***	(70,0$^+$)		P31(1835)		(70,0$^+$)
P11(1880)		(70,2$^+$)				
P11(1975)		(20,1$^+$)				
P13(1720)[b,c]	****	(56,2$^+$)		P33(1600)	***	(56,0$^+$)
P13(1870)[b]	**	(70,0$^+$)		P33(1920)	***	(56,2$^+$)
P13(1910)[a]		(70,2$^+$)	+	P33(1985)		(70,2$^+$)
P13(1950)		(70,2$^+$)				
P13(2030)		(20,1$^+$)				
F15(1680)[c,d]	****	(56,2$^+$)		F35(1905)	****	(56,2$^+$)
F15(2000)[a]	**	(70,2$^+$)		F35(2000)	**	(70,2$^+$)
F15(1995)		(70,2$^+$)				
F17(1990)	**	(70,2$^+$)		F37(1950)	****	(56,2$^+$)

Comparison of Various Models for ω Photoproduction

Y. Oh, A. Titov, and T.-S. H. Lee[1]

In the resonance region, the dominant contributions are from P_{13}(1910) (*missing*) and $N\frac{3}{2}^-$ (identified with D_{13}(2080) of PDG) with lesser contributions from F_{15}(2000) and G_{17}(2190)

A. Titov and T.-S. H. Lee[2]

At threshold ($E_\gamma < 1.25$ GeV), the dominant contributions are from the subthreshold resonance D_{13}(1520) and the near-threshold resonance F_{15}(1680)

Q. Zhao, Z. Li, and C. Bennhold[3]

In the resonance region, the dominant contributions are from P_{13}(1720) and F_{15}(1680). At threshold the low-lying resonance D_{13}(1520) has considerable strength.

All models agree that the π° exchange in the t-channel plays an important role at threshold and in the resonance region. This was first considered by B. Friman and M. Soyeur.[4]

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[1] PRC 63 025201 (2001).
[2] PRC 66 015204 (2002).
[3] PRC 63 025203 (2001) and PRC 58 2393 (1998).
[4] Nucl. Phys. **A600**, 477 (1996)

Comparison of Various Models for ω Photoproduction

G. Penner[1] and U. Mosel – PRC 66, 055212 (2002)

Unitary coupled-channel effective Lagragian approach that incorporates the final states γN, πN, $2\pi N$, ηN, $K\Lambda$, $K\Sigma$, and ωN.

- **The higher partial-wave contributions for π° exchange also dominate the cross section behavior above $\sqrt{s} \simeq 1.82$ GeV.**
- **The resonance $P_{11}(1710)$ dominates at the threshold.**
- **The importance of other resonances is reduced and only the $J^P = \frac{3}{2}^+$ contributions of the $P_{13}(1720)$ and the $P_{13}(1900)$ remain non-negligible.**

All models agree that the π° exchange in the t-channel plays an important role at threshold and in the resonance region.

[1]Ph.D. thesis (in English) "*Vector Meson Production and Nucleon Resonance Analysis in a Coupled Channel Approach*," Universität Gießen, http://theorie.physik.uni-giessen.de

$\gamma p \to \omega p$ Total Cross Section[1]

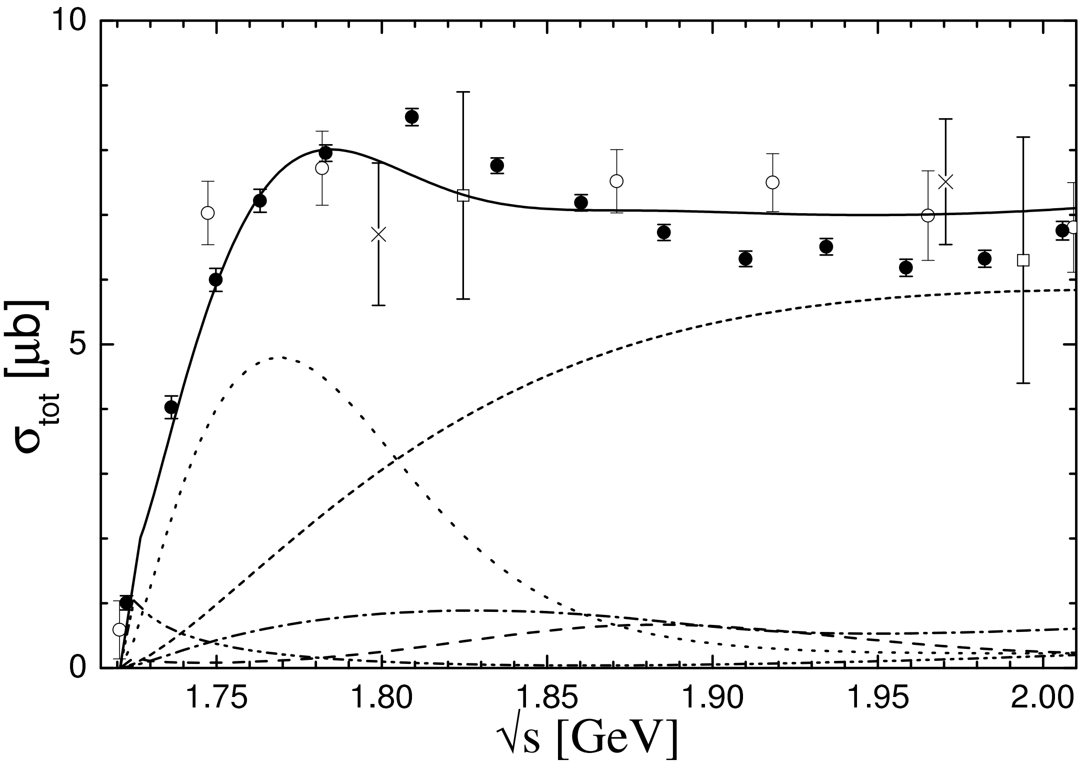

Figure 1: • J. Barth *et al.*, ○ F.J. Klein *et al.*, × ABBHHM, and □ H.R. Crouch *et al.*

The various curves are the partial-wave decomposition from the coupled-channel approach of G. Penner and U. Mosel.

- $J^P = \frac{1}{2}^+ P_{11}(1710)$ resonance.
- $J^P \geq \frac{5}{2}^+$, which stem from π° exchange.
- $J^P = \frac{3}{2}^+$ contributions from the $P_{13}(1720)$ and the $P_{13}(1900)$

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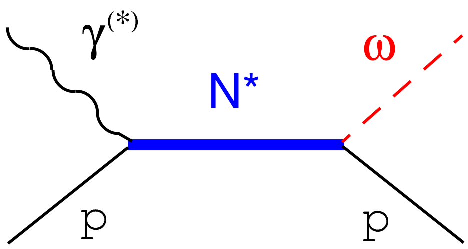
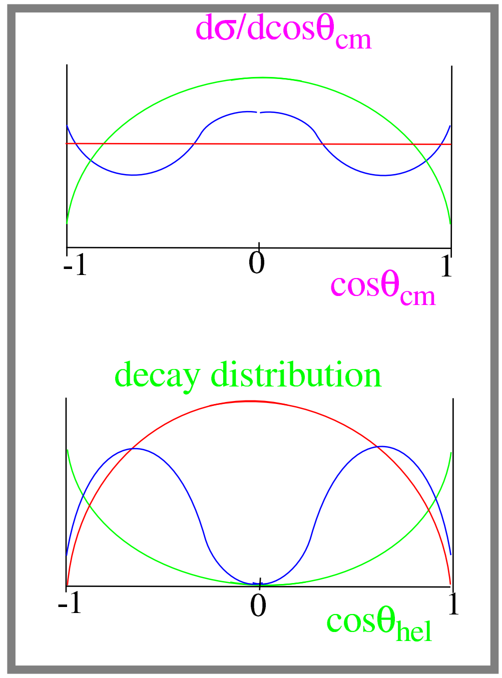
[1] Jens Barth, *"Photoproduktion der Vektormesonen $\omega(782)$ und $\Phi(1020)$ am Proton von Erzeugungschwelle bis zu einer Photon-Energie von 2.6 GeV,"* PhD Thesis (German) BONN-IR-02-06, Bonn University, May 2002, ISSN-0172-8741.
J. Barth *et al.*, *"Low-energy photoproduction of ω-mesons,"* EPJ **18**, 117 (2003)

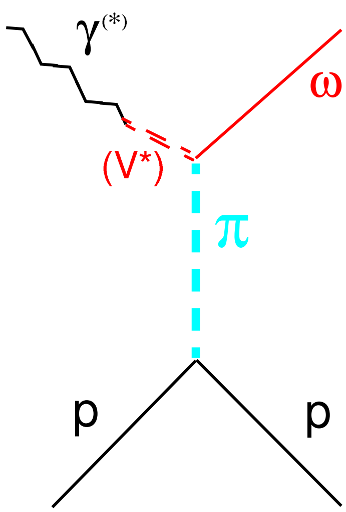
Processes contributing to γp -> ωp

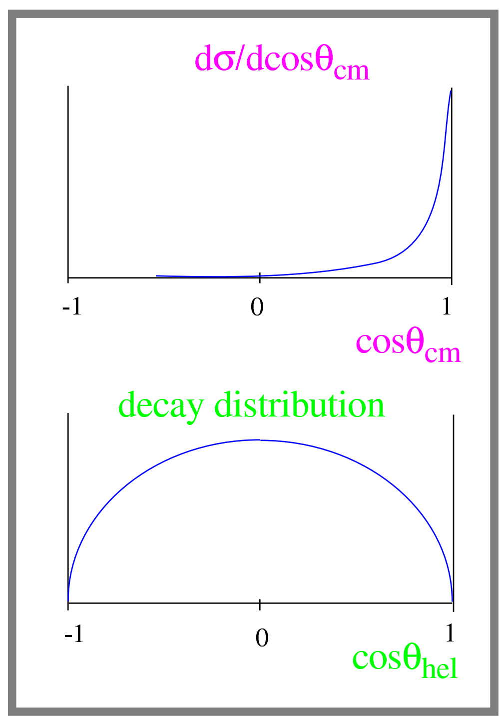
s-channel resonances





t-channel exchanges





$\gamma p \to \omega p$ Differential Cross Section[1]

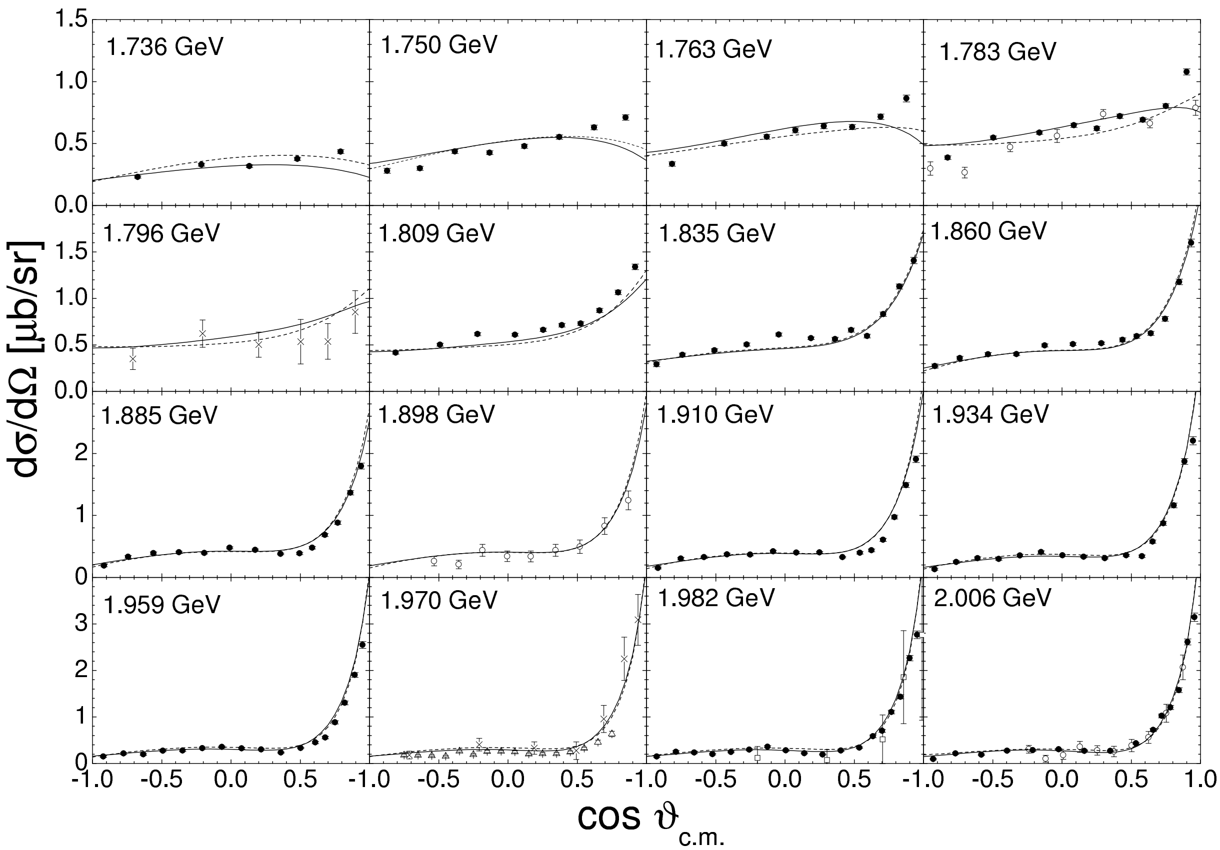


Figure 1: ● J. Barth *et al.*, ○ F.J. Klein *et al.*, × ABBHHM, and □ H.R. Crouch *et al.*, △ J.J. Manak (not used in the fitting procedure).

Above are the W-binned $\gamma p \to \omega p$ differential cross sections. The authors argue that the dominance of the π° exchange mechanism becomes even more pronounced in the differential cross sections. Moreover, the resonance contributions destructively interfere with the pion-exchange as is evidenced in the fits to the SAPHIR data in the central and backward angles.

[1] Jens Barth, *"Photoproduktion der Vektormesonen $\omega(782)$ und $\Phi(1020)$ am Proton von Erzeugungschwelle bis zu einer Photon-Energie von 2.6 GeV,"* PhD Thesis (German) BONN-IR-02-06, Bonn University, May 2002, ISSN-0172-8741.
J. Barth *et al.*, *"Low-energy photoproduction of ω-mesons,"* EPJ **18**, 117 (2003)

Decay Angular Distribution in the Helicity Frame[1]

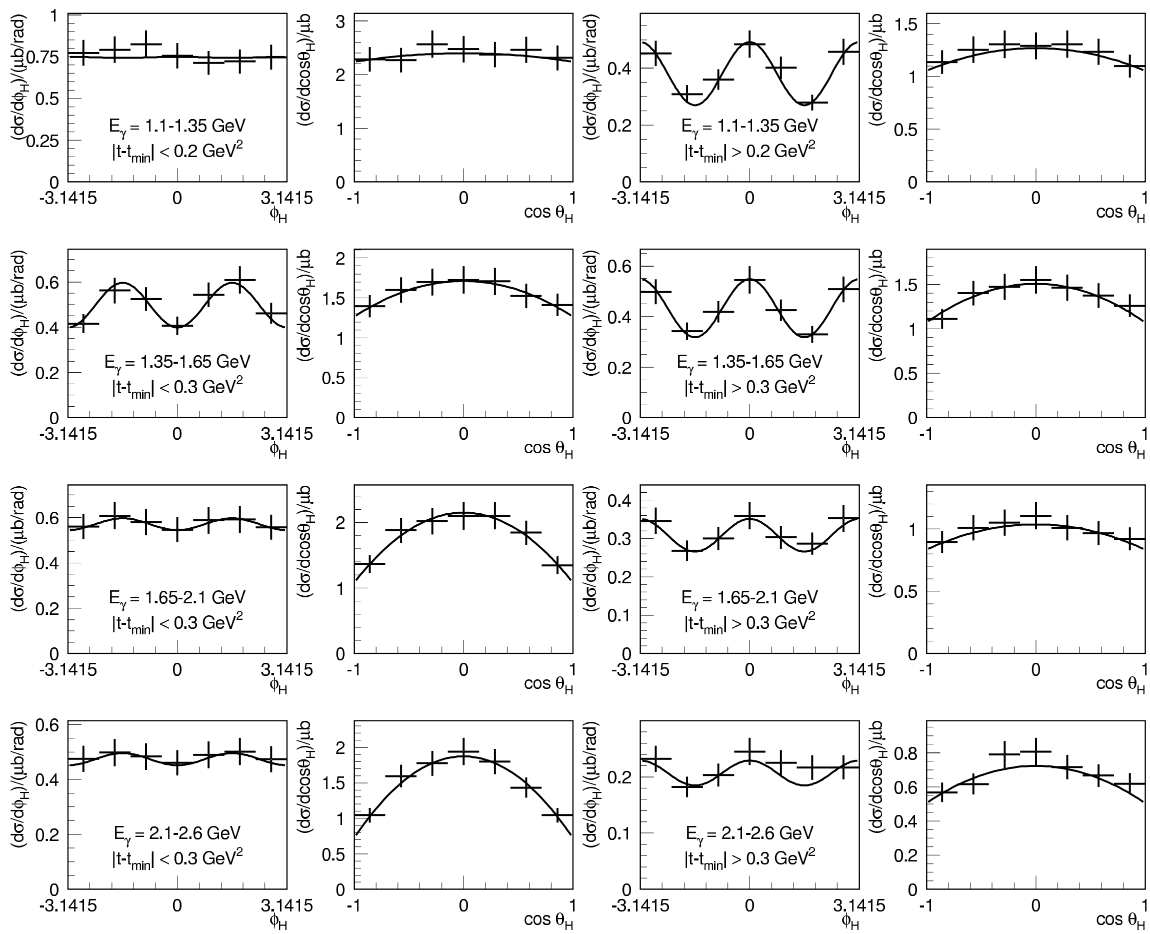


Figure 1: Decay angular distributions in the helicity frame. The two columns on the left show the ϕ and $\cos\theta$ shapes for small $|t|$; the two rightmost columns are the decay distributions at higher $|t|$, or the more central region.

At high energies, s-channel helicity is conserved as evidenced by a $\sin^2\theta_{\rm hel}$ shape in the distributions for $\cos\theta_{\rm hel}$. The SAPHIR group (+ early work from F.J. Klein) observe marked departures from this $\sin^2\theta_{\rm hel}$ behavior at both low and high $|t|$ for energies up to $E_\gamma = 1.65$ GeV. Above this energy of $E_\gamma = 1.65$ GeV ($\sqrt{s} \simeq 2$ GeV), a pronounced deviation from s-channel helicity conservation-like behavior persists for $|t - t_{\rm min}| > 0.3$ GeV^2.

[1] Jens Barth, *"Photoproduktion der Vektormesonen $\omega(782)$ und $\Phi(1020)$ am Proton von Erzeugungschwelle bis zu einer Photon-Energie von 2.6 GeV,"* PhD Thesis (German) BONN-IR-02-06, Bonn University, May 2002, ISSN-0172-8741.
J. Barth *et al.*, *"Low-energy photoproduction of ω-mesons,"* EPJ **18**, 117 (2003)

The Decay Angular Distribution

The complete angular distribution W($\cos\theta, \phi, \Phi$) is given by,

$$
\begin{aligned}
W(\cos\theta, \phi, \Phi) \;=\; W^0(\cos\theta, \phi, \rho^0_{\alpha\beta}) \;&-\; P_\gamma \cos 2\Phi\, W^1(\cos\theta, \phi, \rho^1_{\alpha\beta}) \\
&-\; P_\gamma \sin 2\Phi\, W^2(\cos\theta, \phi, \rho^2_{\alpha\beta}),
\end{aligned}
$$

where

$$
\begin{aligned}
W^0(\cos\theta, \phi, \rho^0_{\alpha\beta}) &= \frac{3}{4\pi}[\frac{1}{2}\sin^2\theta + \frac{1}{2}(3\cos^2\theta - 1)\rho^0_{00} \\
&\quad -\sqrt{2}\,\mathrm{Re}\,\rho^0_{10}\sin 2\theta\cos\phi - \rho^0_{1-1}\sin^2\theta\cos 2\phi] \\
W^1(\cos\theta, \phi, \rho^1_{\alpha\beta}) &= \frac{3}{4\pi}[\rho^1_{11}\sin^2\theta + \rho^1_{00}\cos^2\theta \\
&\quad -\sqrt{2}\,\mathrm{Re}\,\rho^1_{10}\sin 2\theta\cos\phi - \rho^1_{1-1}\sin^2\theta\cos 2\phi] \\
W^2(\cos\theta, \phi, \rho^2_{\alpha\beta}) &= \frac{3}{4\pi}[\sqrt{2}\,\mathrm{Im}\,\rho^2_{10}\sin 2\theta\sin\phi + \mathrm{Im}\,\rho^2_{1-1}\sin^2\theta\sin 2\phi],
\end{aligned}
$$

and θ and ϕ are the polar and azimuthal angles of the normal to decay plane of $\omega \to \pi^+\pi^-\pi^\circ$ wrt to the quantization axis, and P_γ is the degree of linear polarization.

By using *linearly polarized* photons, we are sensitive to six additional density matrix elements, providing a total of nine constraints for extracting the helicity amplitudes.

What are the Density Matrix Elements?

Density matrix elements, are related to the *helicity amplitudes*.

$$(\rho^0, \rho^n) \;=\; \mathbf{H}(\frac{1}{2}\mathbf{I}, \frac{1}{2}\sigma^n)\mathbf{H}^\dagger \qquad n \;=\; 1, 2, 3$$

where $\mathbf{H}$ is the helicity amplitude matrix, and σ^n are the Pauli spin matrices.

The *density matrix elements* can be written as a sum of bilinear combinations of the *helicity amplitudes*. (The summation over the nucleon spins is implied). For the unpolarized case:

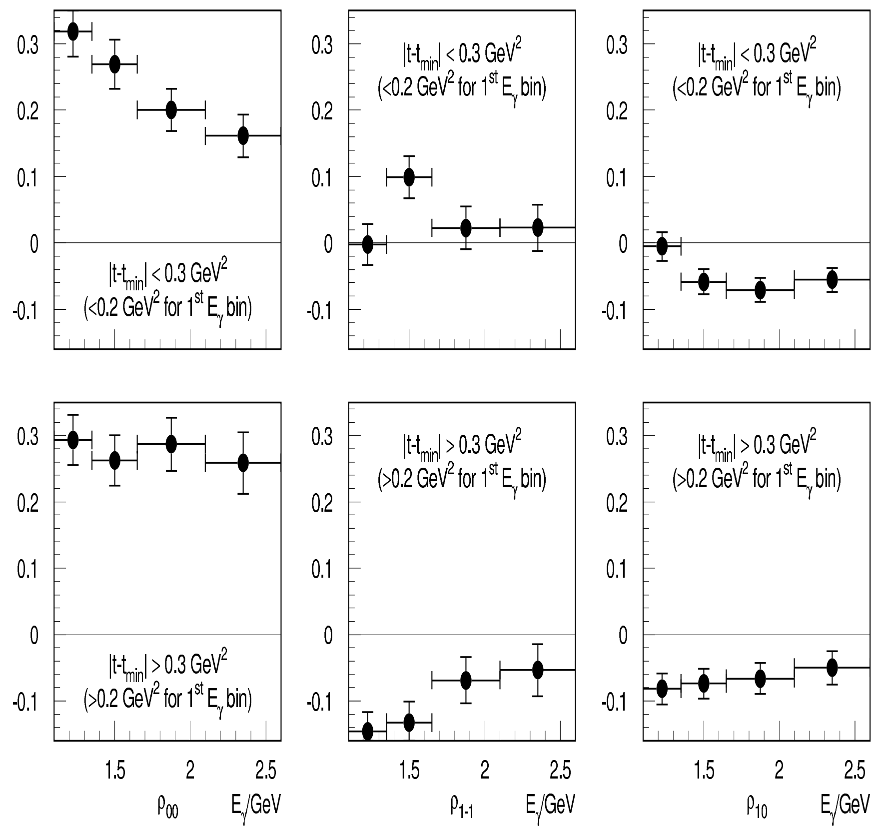
$$\rho^0_{\lambda_\rho \lambda'_\rho} = \sum_{\lambda_\gamma \lambda''_\gamma} H_{\lambda_\rho \lambda_\gamma} H^*_{\lambda_\rho \lambda''_\gamma}, \qquad \lambda_\gamma, \lambda''_\gamma = 1, -1$$

Some Examples

ρ^0_{00} measures the intensity of the helicity flip by one unit at the $\gamma\omega$ vertex, i.e., $\rho^0_{00} \sim |H_{01}|^2 + |H_{0-1}|^2$.

ρ^0_{1-1} measures the interference of nonflip and double-flip amplitudes, i.e., $\rho^0_{1-1} \sim H_{11} H^*_{-11} + H_{1-1} H^*_{-1-1}$.

Spin Density Matrix Elements (Helicity Frame)[1]



- For *unnatural-parity* (π°) exchange, the spin operator does not flip the helicity of the photon, *i.e.* the transition from $\lambda_\gamma = \pm 1$ to $\lambda_V = 0$ vanish.
- For *natural-parity* (Pomeron) exchange in the diffractive process, all but two of the density matrix elements vanish.

Hence for 0^+ (Helicity Frame) and 0^- (Gottfried-Jackson Frame) exchanges all but the ρ^1_{1-1} and $Im\rho^2_{1-1}$ density matrix elements are ZERO. Therefore: ρ^0_{00}, ρ^0_{10}, and ρ^0_{1-1} should be ZERO. **They are not.**

[1] Jens Barth, *"Photoproduktion der Vektormesonen $\omega(782)$ und $\Phi(1020)$ am Proton von Erzeugungschwelle bis zu einer Photon-Energie von 2.6 GeV,"* PhD Thesis (German) BONN-IR-02-06, Bonn University, May 2002, ISSN-0172-8741.
J. Barth *et al.*, *"Low-energy photoproduction of ω-mesons,"* EPJ **18**, 117 (2003)

Yongseok Oh, Alexander I. Titov, and T.-S. H. Lee[1]

This collaboration employs $N^* \to \gamma N$ and $N^* \to \omega N$ amplitudes. These amplitudes include configuration mixing effects due to quark-quark interactions. They employ the resonance parameters predicted by Simon Capstick and Winston Roberts[2]

- Pomeron exchange governs the total cross sections and differential cross sections at low $|t|$ for high E_γ. The model parameters are determined by fitting all the total cross sections for ω, ρ, and ϕ at higher energies, such as the parameter $\beta_\circ$ in the strength factor in the Regge parameterization for Pomeron exchange.

- At low energies, the π exchange completely dominates the cross sections at forward angles. The cutoff parameters $\Lambda_{\pi NN}$ and $\Lambda_{\omega\gamma\pi}$ are incorporated in form factors to dress the πNN and $\omega\gamma\pi$ vertices. These parameters come from fits to the data.

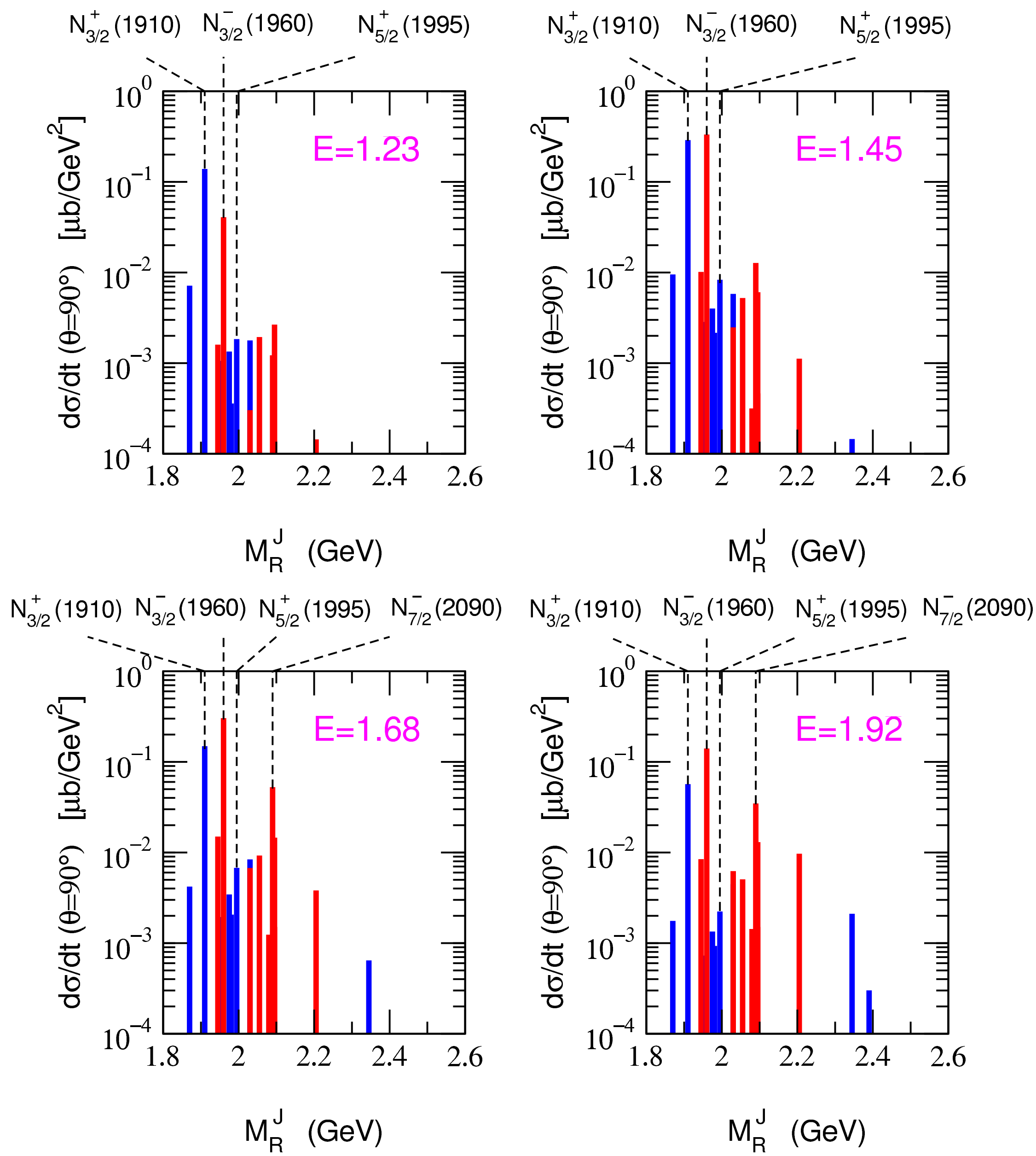
- They include baryon resonances by using the Breit-Wigner descriptions with vertex functions provided by the relativized pair-creation ($^3P_0$) quark model of Capstick/Roberts.

- The domininant contributions are found to be from the $N\frac{3}{2}^+P_{13}(1910)$ *missing* resonance and the $N\frac{3}{2}^-(1960)$, which is identified as the resonance $D_{13}(1910)$ of the PDG.

[1] *"Nucleon Resonance in ω photoproduction,"* Phys. Rev. **C63**, 025201 (2001)
[2] Phys. Rev. **D46**, 2864 (1992); Phys. Rev. **D49**, 4570 (1994)

model Y.Oh:

Resonant contribution to ω photoproduction at $\theta = 90°$



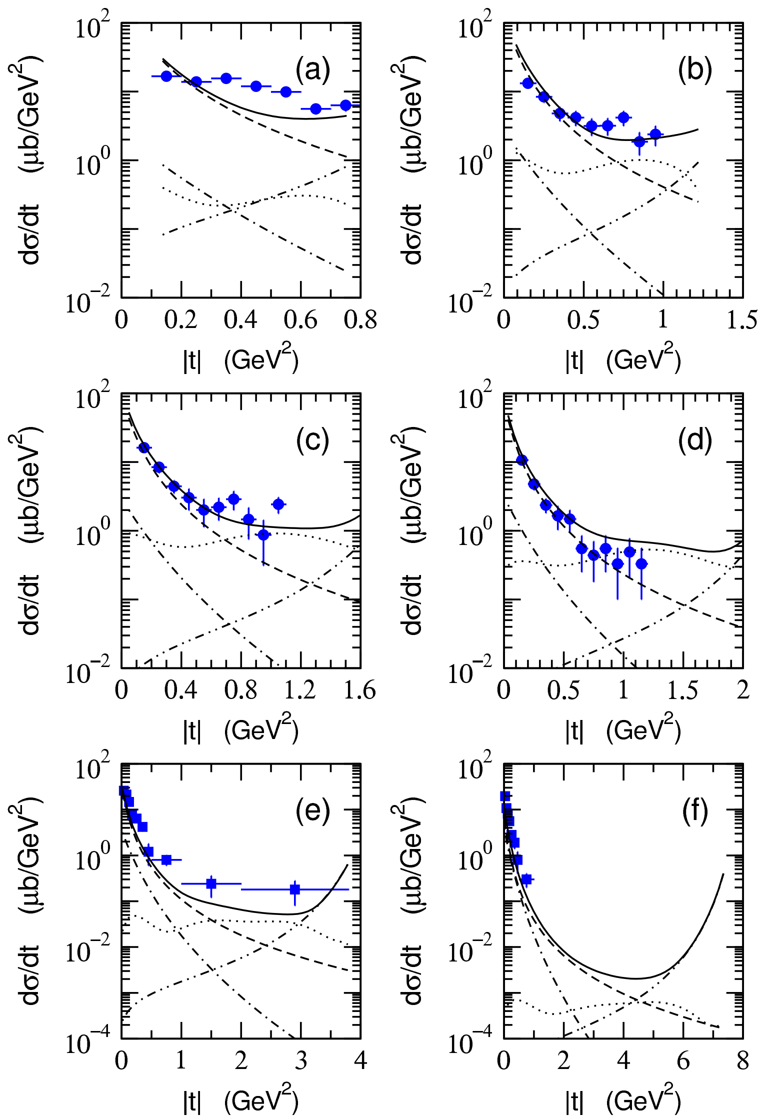


FIG. 2. Differential cross sections for $\gamma p \to p\omega$ reaction as a function of $|t|$ at $E_\gamma =$ (a) 1.23, (b) 1.45, (c) 1.68, (d) 1.92, (e) 2.8, and (f) 4.7 GeV. The results are from pseudoscalar-meson exchange (dashed), Pomeron exchange (dot-dashed), direct and crossed nucleon terms (dot-dot-dashed), N^* excitation (dotted), and the full amplitude (solid). Data are taken from Ref. [32] (filled circles) and Ref. [12] (filled squares).

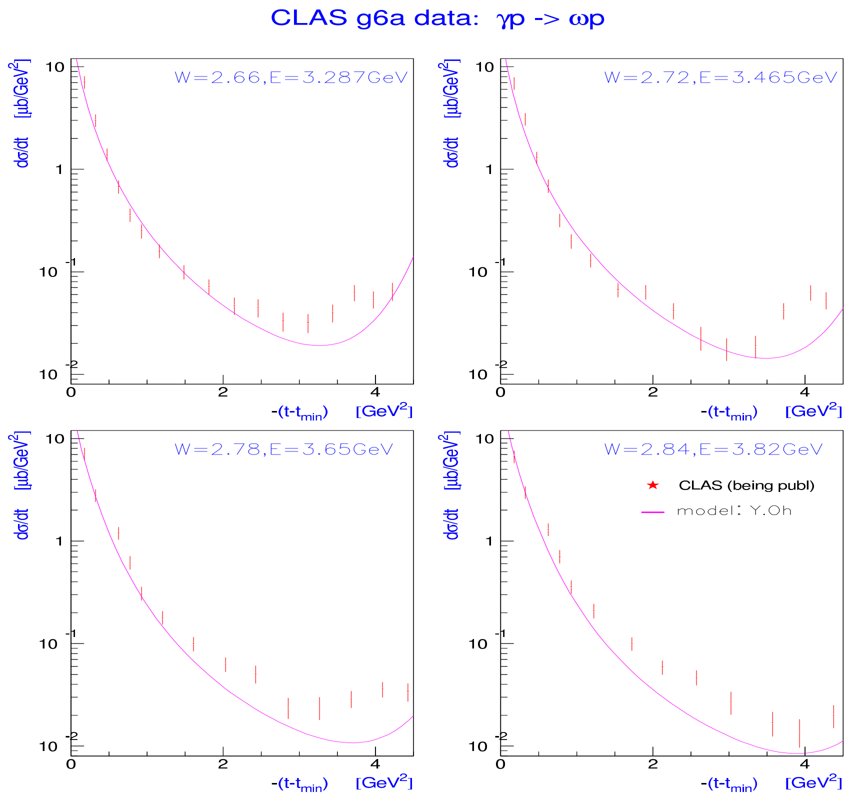


Figure 1: Model Parameters: (Pomeron Exchange): $\beta_\circ$: $2.05 \to 2.3$ GeV^{-1} (OPE): $\Lambda_{\pi NN}$: $0.60 \to 0.70$ GeV and $\Lambda_{\omega\gamma\pi}$: $0.70 \to 0.77$ GeV. Analysis by Franz Klein, Catholic University of America.

Model: Yongseok Oh, Alexander I. Titov, and T.-S. H. Lee[1].

SUM = (OPE + Pomeron) + N* (Capstick/Roberts Model)[2]

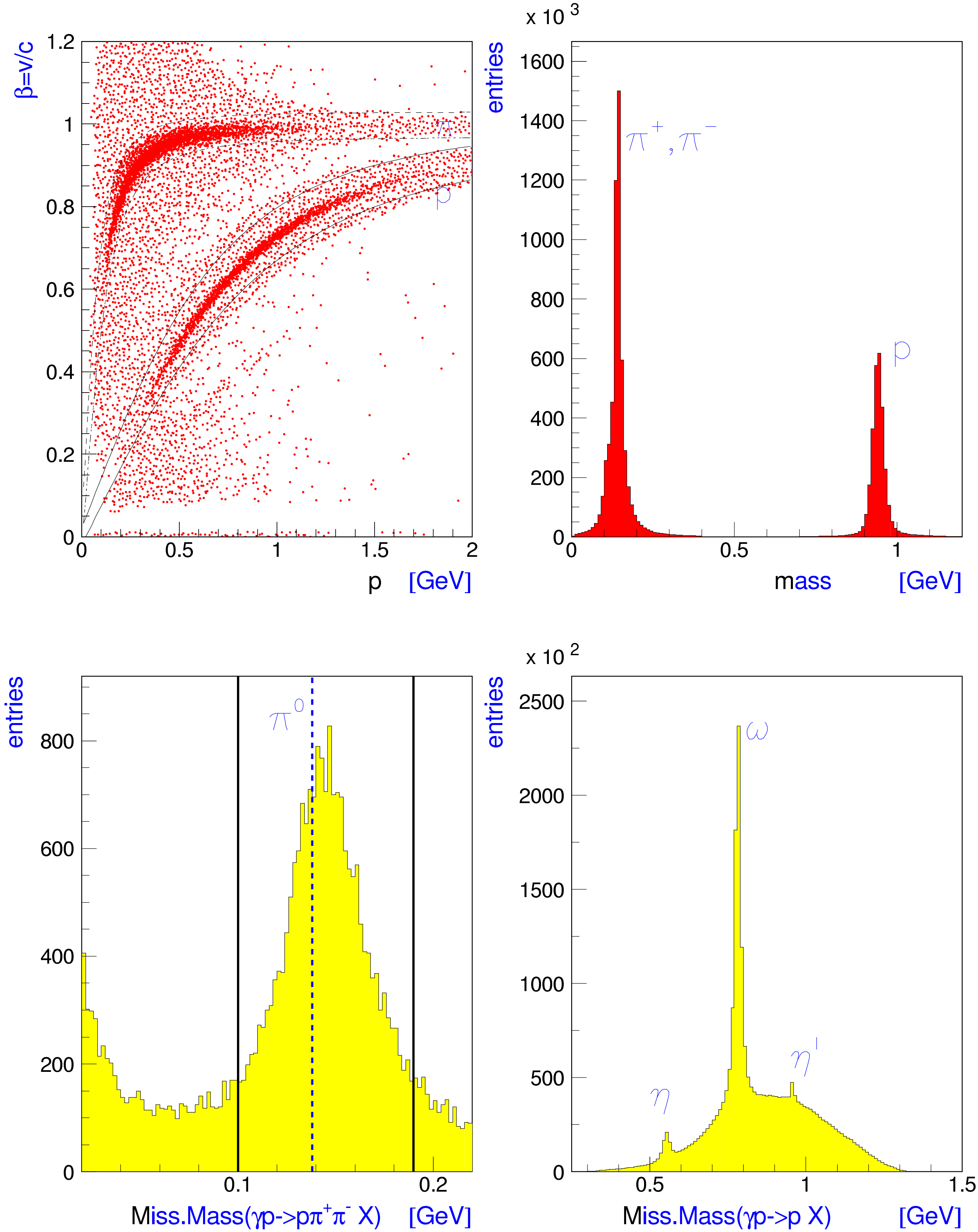
Strength Factor $C_V = 12\sqrt{4\pi\alpha_{\rm em}}\beta_\circ^2/f_V$ (The decay constant $f_\omega = 17.05$)

The Form Factor to dress the πNN vertex $F_{\pi NN}(t) = \frac{\Lambda_{\pi NN}^2 - M_\pi^2}{\Lambda_{\pi NN}^2 - t}$

The Form Factor to dress the $\omega\gamma\pi$ vertex $F_{\omega\gamma\pi}(t) = \frac{\Lambda_{\omega\gamma\pi}^2 - M_\pi^2}{\Lambda_{\omega\gamma\pi}^2 - t}$

[1] Phys. Rev. **C63**, 025201 (2001)
[2] Phys. Rev. **D46**, 2864 (1992); Phys. Rev. **D49**, 4570 (1994)

CLAS g1c data: process ident.



CLAS: $\gamma p \rightarrow \omega p$[1]

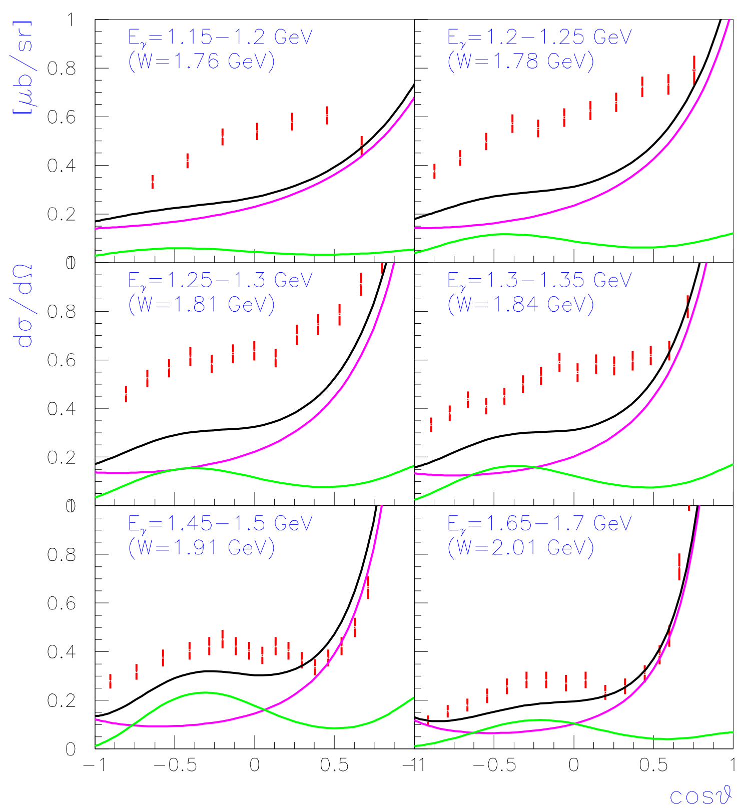


Figure 1: $\cos\theta = \mathbf{k}\cdot\mathbf{q}/|\mathbf{k}||\mathbf{q}|$. Here k and q are the four momenta of the incoming photon and the outgoing ω, respectively.

Model: Yongseok Oh, Alexander I. Titov, and T.-S. H. Lee[2].

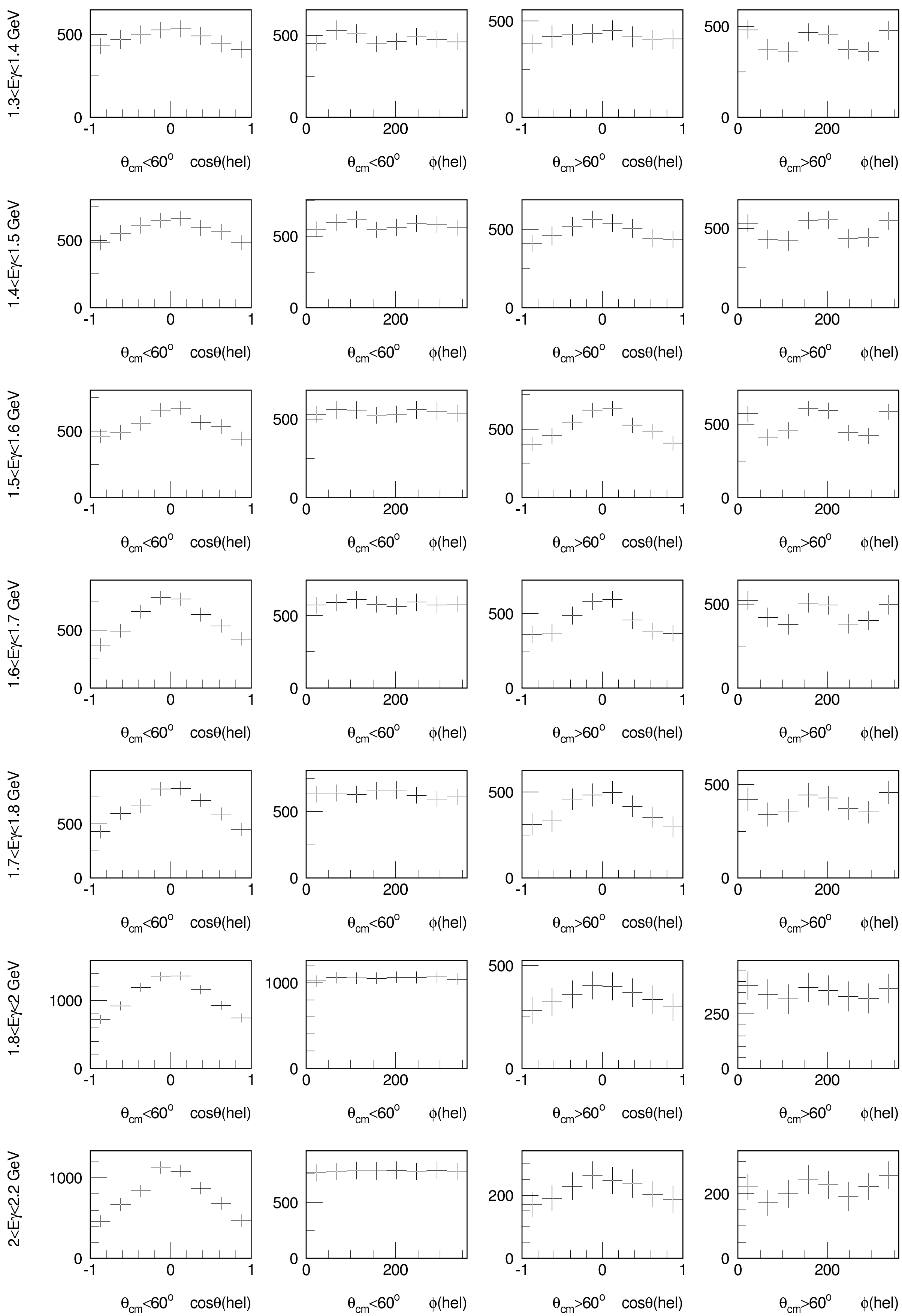
SUM = (OPE + Pomeron) + N* (Capstick/Roberts Model)[3]

[1] Analysis by Franz Klein, Catholic University of America.

[2] Phys. Rev. **C63**, 025201 (2001)

[3] Phys. Rev. **D46**, 2864 (1992); Phys. Rev. **D49**, 4570 (1994)

γp -> ωp : decay (hel.)



Qiang Zhao, Zhenping Li, and Cornelius Bennhold[1]

This collaboration employs effective Lagrangians for both the quark-photon and the quark-vector-meson interaction. The resonances are explicitly included in the basis of the SU(6)⊗O(3) symmetric quark model. Although the vector mesons are treated as point-like particles, their size effects are partially taken into account through the baryon wavefunctions.

- Pomeron exchange (*natural-parity*) in the diffractive process

  This process dominates above the resonance region in the total cross section and itis forward peaking in the differential cross sections.

- Pion exchange (*unnatural-parity*)

  This process dominates over a wide energy range above the vector meson production threshold, and is also forward-peaking.

- Resonances

  s- and u-channel transitions through effective Lagrangians for the quark-photon and quark-vector-meson interaction. Apart from factors from spin, isospin, and spatial wavefunctions, all the baryons share the same factors for quark-vector-meson coupling strengths.

  In the SU(6)⊗O(3) symmetry limit, eight resonances, $S_{11}(1535)$, $D_{13}(1520)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $F_{15}(1680)$, $P_{13}(1900)$, & $F_{15}(2000)$, are explicitly included in the s-channel apart from the Born terms. Near threshold, the dominant contributions arise from the $P_{13}(1720)$ and the $F_{15}(1680)$, but the $D_{13}(1520)$ has sizeable strength as well. The effects from the $P_{13}(1900)$ and the $F_{15}(2000)$ are relatively suppressed.

[1]Phys. Lett. B **B43**, 42 (1998); PRC **58**, 2393 (1998); PRC **63**, 025203 (2001).

$\gamma p \longrightarrow \omega p$ (GRAAL)[1]

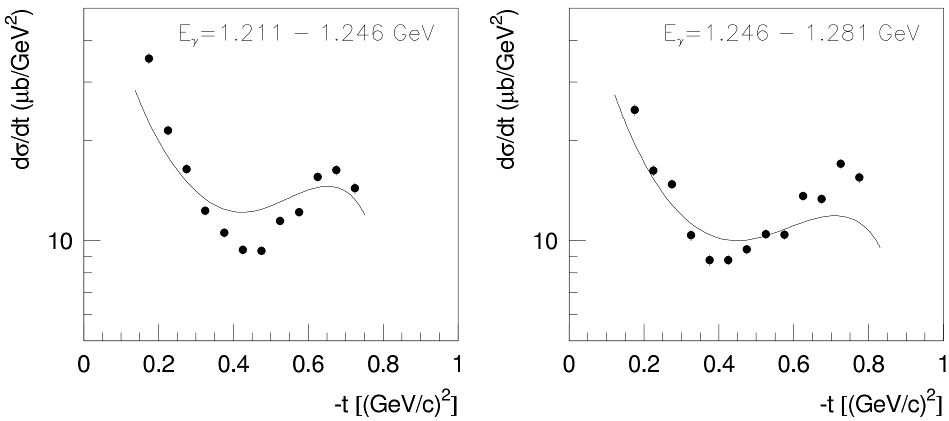


Figure 1: $\gamma p \longrightarrow \omega p$ differential cross sections.

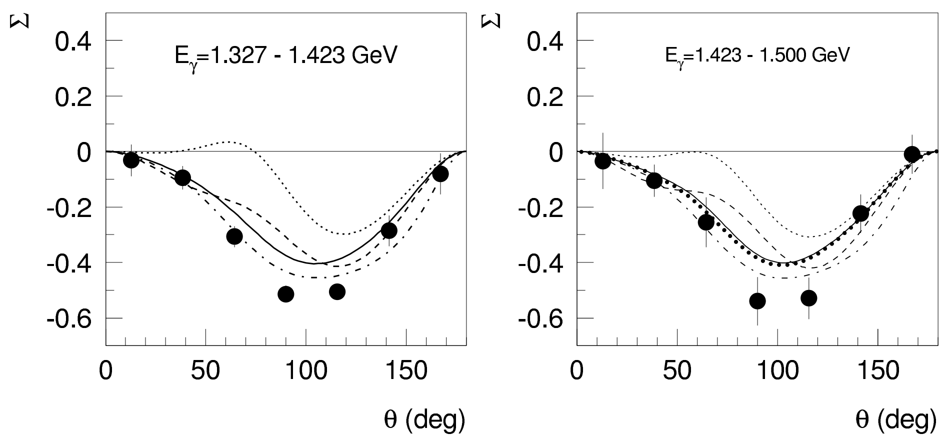
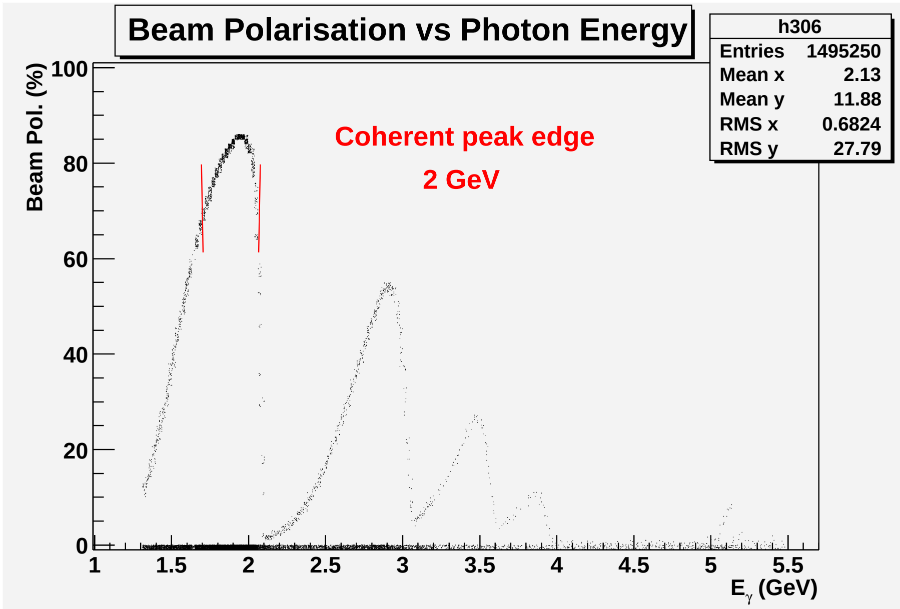


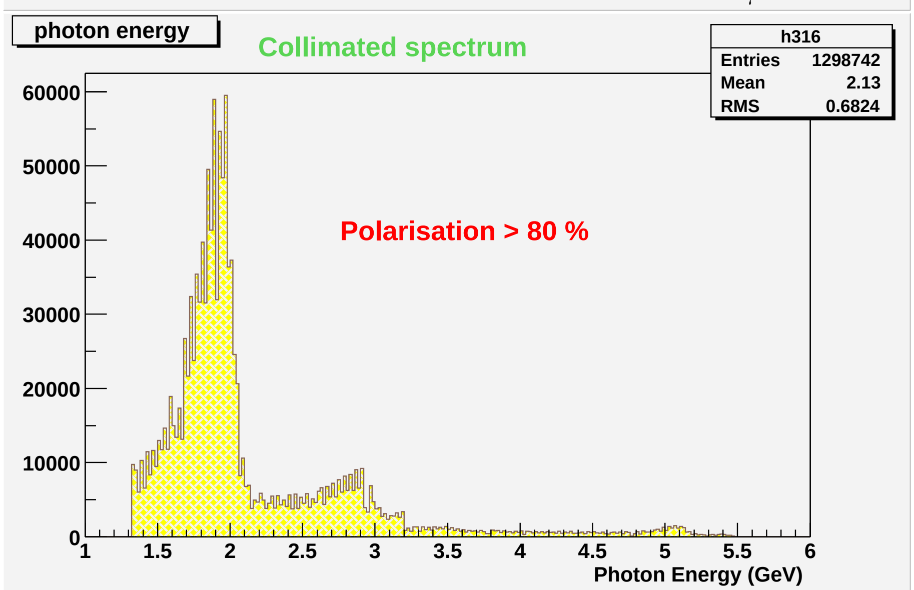
Figure 2: Beam asymmetry as a function of c.m. polar angle at two different energies for $\gamma p \longrightarrow \omega p$. The model calculations are from Q. Zhao *et al.*. full calculation with all resonances, $D_{13}(1520)$ absent, $P_{13}(1720)$ absent, and $F_{15}(1680)$ absent

Eight resonances, $S_{11}(1535)$, $D_{13}(1520)$, $P_{11}(1440)$, $P_{11}(1710)$, $P_{13}(1720)$, $F_{15}(1680)$, $P_{13}(1900)$, & $F_{15}(2000)$, are explicitly included in the Zhao, Li, and Bennhold Model. In this model, the polarization observable Σ is particularly sensitive to the presence or absence of the resonances: $P_{13}(1720)$, $F_{15}(1680)$, and $D_{13}(1520)$ as evidenced in Fig. 2.

[1] Y. Assafiri *et al.*, GRAAL Collaboration, Proceedings of NSTAR2002

Photon Energy and Beam Polarisation

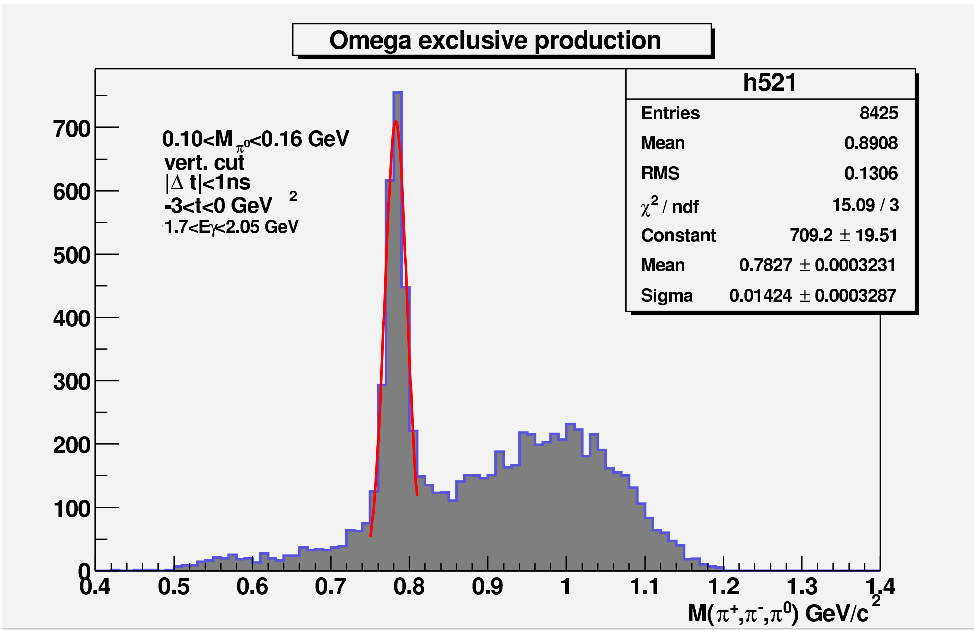


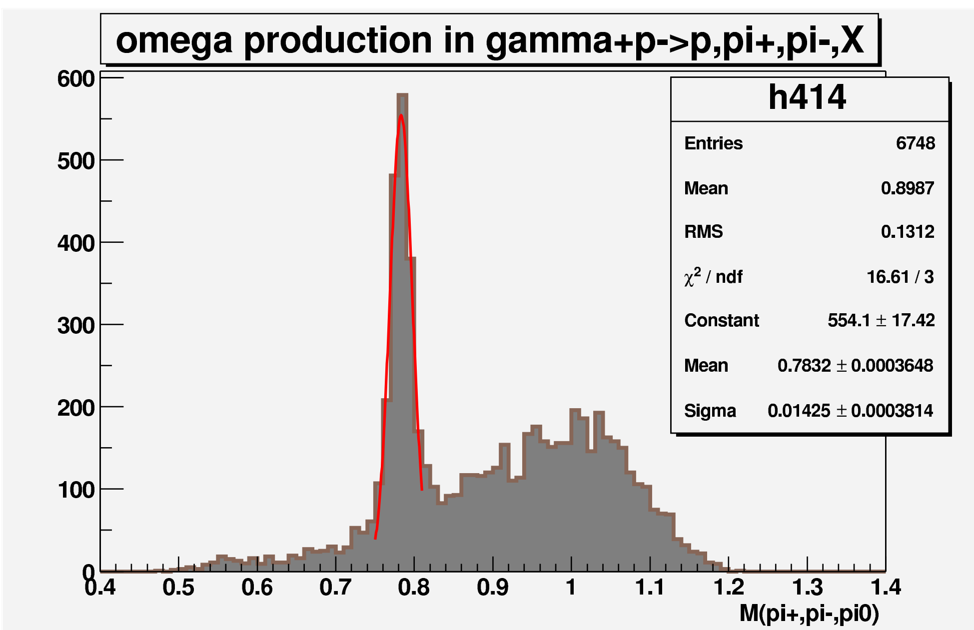


-1.70 GeV $\geq E_\gamma \leq$ 2.05 GeV

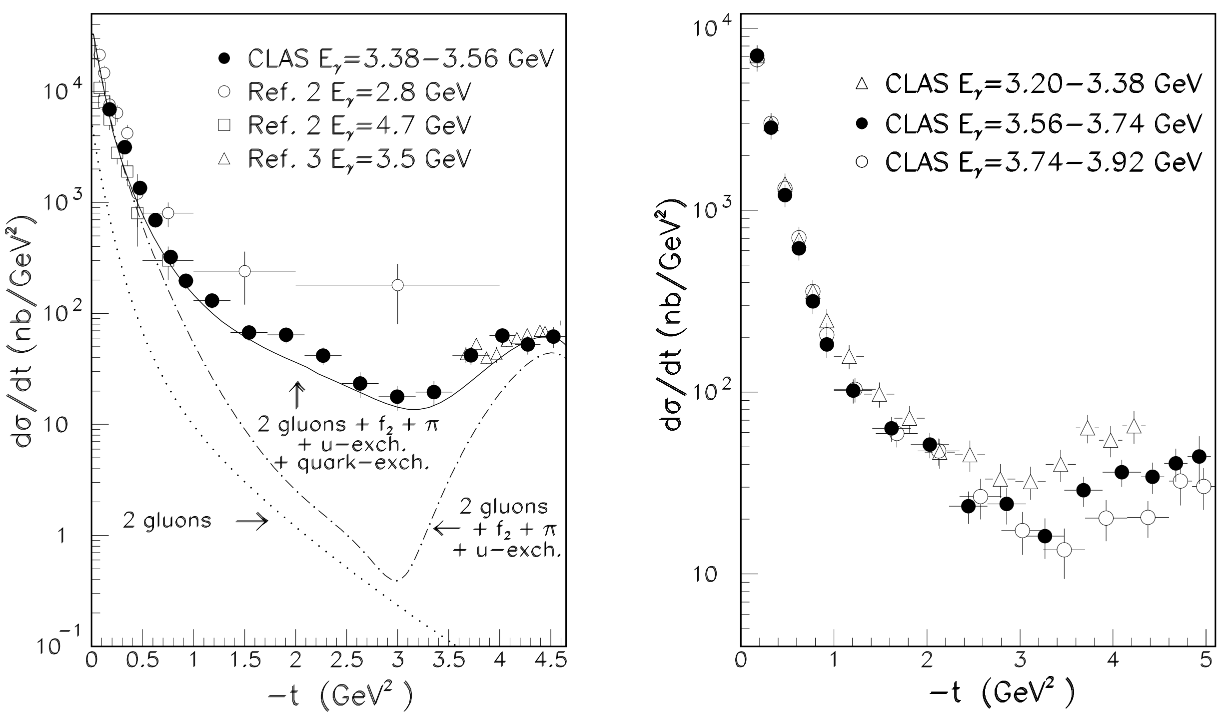
Average polarisation for this range is about 80%.

Exclusive and Inclusive ω spectrum





CLAS $\gamma p \to \omega p$ $(3.19 < E_\gamma < 3.92$ GeV)[1]



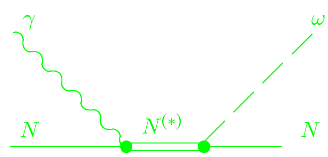
Above is plotted predictions of a QCD-inspired model.[2] Here the Pomeron exchange has been replaced by the exchange of two nonperturbatively dressed gluons. The low-momentum transfer region is dominated by pion exchange. Adding in the effects of two-gluon and $f_2(1270)$ trajectory exchanges – coupled with u-channel exchange in the nucleon Regge trajectory[3] – gives good agreement to the differential cross section.

[1] M. Battaglieri *et al.*, "*Photoproduction of the ω Meson on the Proton at Large Momentum Transfer,*" PRL **90** 2, 022002 (2003).

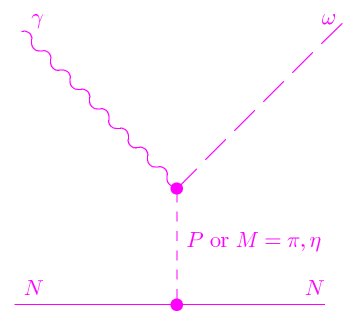
[2] J.M. Laget, Phys. Lett. B **489**, 313 (2000); F. Cano and J.M. Laget, PRC **65**, 074022 (2002)

[3] M. Guidal, J.M. Laget, and M. Vanderhaeghen, Nucl. Phys. **A627**, 645 (1997).

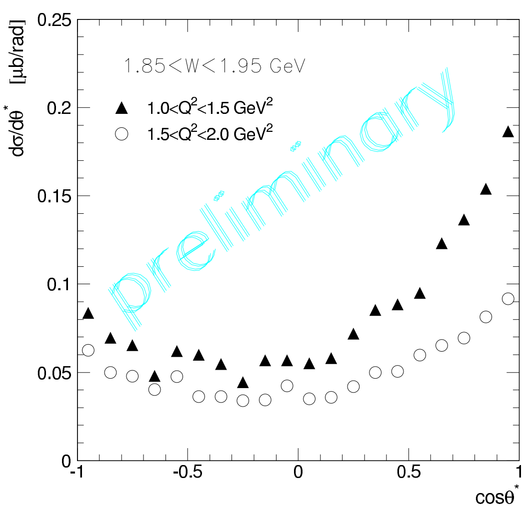
CLAS: $\gamma^* p \to \omega p \quad E_\circ = 4.2$ GeV [1]



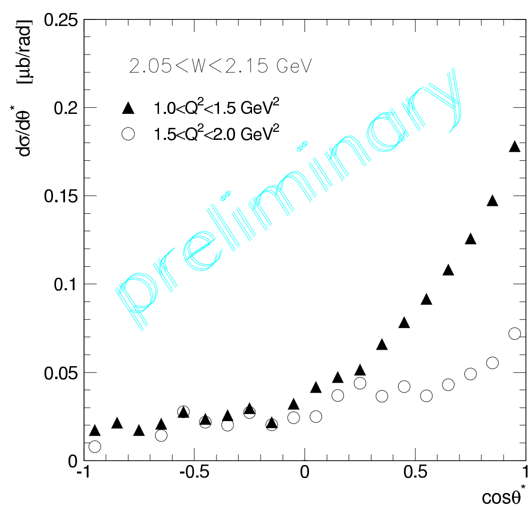
s-channel baryon exchange



t-channel meson exchange/diffractive scattering



Within Resonance Region



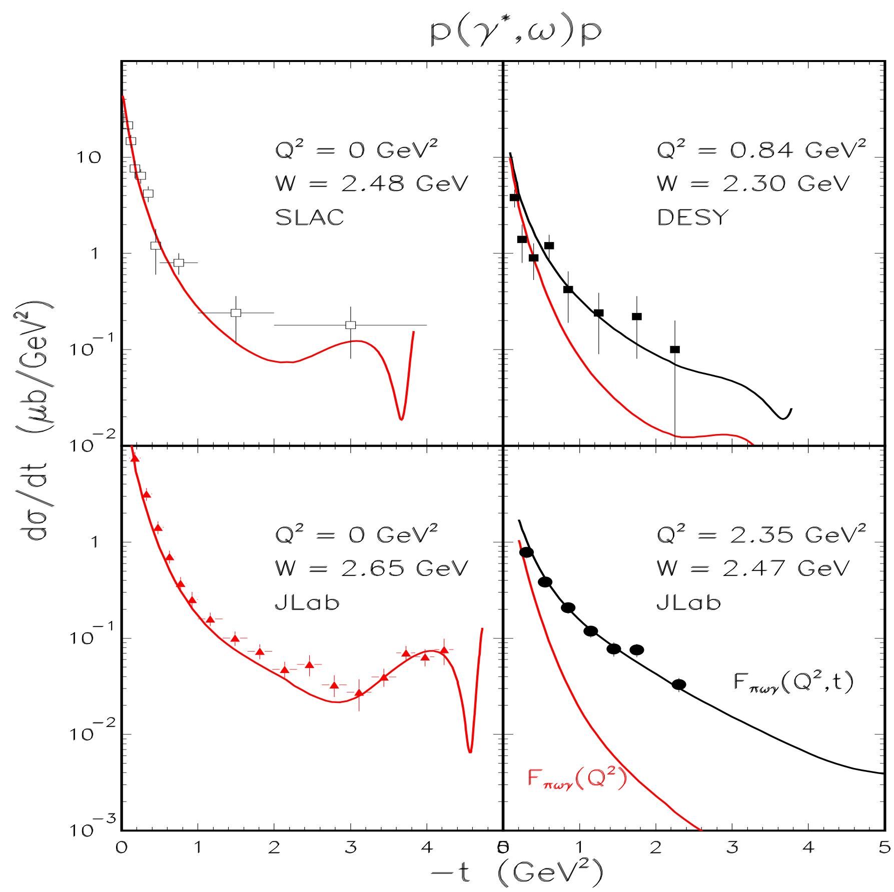
Above Resonance Region

We see that in the **resonance region** of $\mathbf{1}.85 < W < 1.95$ **GeV**, there is an excess of cross section for $\cos\theta_{\mathbf{p}\omega} < \mathbf{0}$, which cannot be explained by either natural- or unnatural-parity exchange mechanisms.

[1] Franz Klein, Catholic University of America, *unpublished*

CLAS: $\gamma^* p \rightarrow \omega p$ [1]

A Regge-based model[2] – where the dominant process is π° production – reproduces the data quite well. Introducing a t dependence in the $\pi\omega\gamma$ form factors suggests a point-like coupling at higher values of $|t|$.



Differential cross sections $d\sigma/dt$: photoproduction **(left graphs)**, DESY: $W = 2.30$ GeV with $Q^2 = 2.30$ GeV^2 **(upper right)**, and Preliminary CLAS data: $W = 2.47$ GeV with $Q^2 = 2.35$ GeV^2 **(lower right)**; The curves are from the JML model: in red, $F_{\pi\omega\gamma}$ form factor, in black, with an additional t dependence in the form factor.

[1] Ludyvine Morand, "Mesure de l'electroproduction de mésons omega à grand transfert d'énergie-impulsion," l'Université Paris 7 – Denis Diderot, 19 Dec. 2003, *unpublished*;
JLab Experiment 99-105, M. Guidal, M. Garçon, and E. Smith, spokespersons.

[2] J.-M. Laget, to be published

CLAS: $\gamma^* p \longrightarrow \omega p$ [3]

PRELIMINARY CONCLUSIONS

- The cross sections are unexpectedly high at large values of $|t|$.
  - s-channel helicity is not conserved
  - σ_L and σ_T cannot be separated using only the ω decay parameters.
- Unnatural parity exchange in the t channel. The π° exchange dominates over the kinematical range for $E_\circ = 6.0$ GeV.

The results from Ludyvine Morand's thesis are under review by the CLAS Collaboration. We expect to publish these results by the end of the 2004.

[3] Ludyvine Morand, "Mesure de l'electroproduction de mésons omega à grand transfert d'énergie-impulsion," l'Université Paris 7 – Denis Diderot, 19 Dec. 2003, *unpublished*,
JLab Experiment 99-105, M. Guidal, M. Garçon, and E. Smith, spokespersons.

SUMMARY

In the resonance regime, $m_N < W \leq 2$ GeV, experimentally:

- **The unpolarized photoproduction data from SAPHIR have been published.**
- **Analysis of the unpolarized data from CLAS (g1c), electroproduction data (e6) and the linearly-polarized data from GRAAL and CLAS (g8a) is underway. Results to be published**

From theory:

- All models agree **that π° exchange (*unnatural parity*) in the t channel plays a significant role in the cross section of the electro- and photoproduction of omega mesons**
- All models agree **that baryon resonances contribute significantly to both the total and differential cross section in omega electro- and photoproduction.**
- All models agree **that we urgently need polarization observables to disentangle which resonances and by how much these resonances contribute to the cross section.**

The models, however, do not agree with one another.

Different models predict

- differing relative contributions of *unnatural-* and *natural-parity* exchange in the t channel.
- differing contributions of the resonances.

Question: What are the best set of observables obtained from double or triple polarization experiments, which may serve to best disentangle the relative contributions of the various resonances?