N*2002, Pittsburgh, USA

THE GLASGOW PION PHOTOPRODUCTION PARTIAL WAVE ANALYSIS, 2002

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THE AIM

- To get the γN couplings of the N^* and Δ resonances from experimental data for single pion photoproduction.
- If possible, to measure the resonance masses and widths from photoproduction data.
- To search for suspected resonances.
- Basically, to extract as much information from photoproduction data as possible.

THE INPUT

- Analyticity in the form of fixed-t dispersion relations
- Resonance dominance of the imaginary parts of the production amplitudes
- A little Regge theory
- Watson's theorem across the first resonance region, including the complex phase of the $\Delta(1232)$
- Non-resonant background for the imaginary parts of the S11, S31, P11, P13 and P31 partial waves (especially the S waves.)
- A data base with over 20,000 experimental measurements
- All known or suspected resonances with masses below 2.5 GeV.

4

		πN	γN
P11	N*(1440)	****	***
D13	N*(1520)	****	****
S11	N*(1535)	****	***
P13	N*(1550)	??	??
S11	N*(1650)	****	***
D15	N*(1675)	****	****
F15	N*(1680)	****	***
D13	N*(1700)	***	**
P11	N*(1710)	***	***
P13	N*(1720)	****	**
P13	N*(1900)	**	
D13	N*(1910)	**	??
F17	N*(1990)	**	*
F15	N*(2000)	**	
D13	N*(2080)	**	*
S11	N*(2090)	*	
P11	N*(2100)	*	
G17	N*(2190)	****	*
D15	N*(2200)	**	
G19	N*(2250)	****	
H19	N*(2250)	****	

	πN	γN
P33 Δ(1232)	****	****
P31 Δ(1540)	??	??
P33 Δ(1600)	***	**
S31 Δ(1620)	****	***
D33 Δ(1700)	****	***
P31 Δ(1750)	*	
S31 Δ(1900)	**	*
F35 Δ(1905)	****	***
P31 Δ(1910)	****	*
P33 Δ(1920)	***	*
D35 Δ(1930)	***	**
D33 Δ(1940)	*	
F37 Δ(1950)	****	****
F35 Δ(2000)	*	
S31 Δ(2150)	*	
G37 Δ(2200)	****	
H39 Δ(2300)	**	
D35 Δ(2350)	*	
F37 Δ(2390)	*	
G39 Δ(2390)	*	
H3,11Δ(2420)	****	*

Fixed-t dispersion relations

The real and imaginary parts of the Lorentz invariant amplitudes, A(s,t) are linked by

$$\mathrm{Re}\,A(s,t) = A_{Born}(s,t) + \frac{1}{\pi} P \int_{s_0}^{\infty} ds' \,\mathrm{Im}\,A(s' t) \left[\frac{1}{s'-s} + \frac{\eta}{s'-u} \right]$$

Here, η is ± 1 depending on the s-u crossing symmetry of A(s,t).

		πN	γN
P33	Δ(1232)	****	****
P31	Δ(1540)	??	??
P33	Δ(1600)	***	**
S31	Δ(1620)	****	***
D33	Δ(1700)	****	***
P31	Δ(1750)	*	
S31	Δ(1900)	**	*
F35	Δ(1905)	****	***
P31	Δ(1910)	****	*
P33	Δ(1920)	***	*
D35	Δ(1930)	***	**
D33	Δ(1940)	*	
F37	Δ(1950)	****	****
F35	Δ(2000)	*	
S31	Δ(2150)	*	
G37	Δ(2200)	****	
H39	Δ(2300)	**	
D35	Δ(2350)	*	
F37	Δ(2390)	*	
G39	Δ(2390)	*	
H3,11	Δ(2420)	****	*

- Using fixed-t dispersion relation, the real part of the amplitudes are given by the imaginary parts. There is no need to parametrise and fit them separately.
- Additionally, the correlation between structures in the real and imaginary parts, required by analyticity is automatically built in.

The Born terms are simple poles without added form factors.

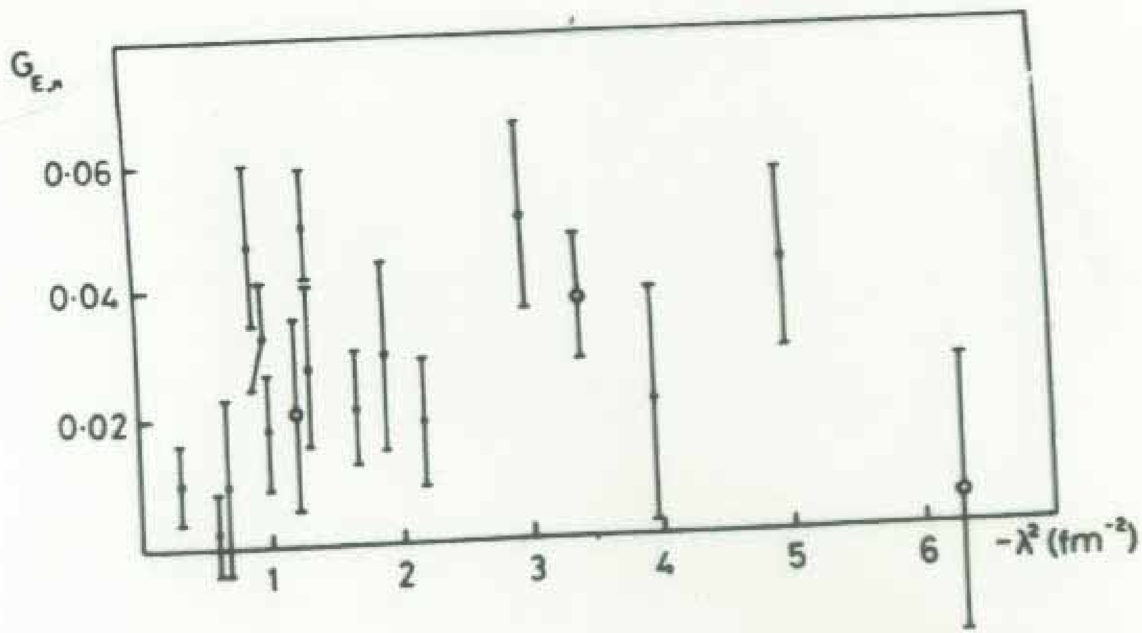


Fig. 9. The neutron charge form factor. The open circles are the results of this calculation and the solid circles are from electron-deuteron scattering [20].

Photon decay couplings

The analysis measures the helicity amplitudes for $\gamma N \to \pi N$, $A_{\ell\pm}$ and $B_{\ell\pm}$, but the results are usually given in terms of the decay couplings to gN, $A_{1/2}$ and $A_{3/1}$. These are related by

$$A_{\ell\pm} = \mp\alpha C_{\pi N} A_{1/2}$$

$$B_{\ell\pm} = \pm\frac{4\alpha}{\sqrt{(2j-1)(2j+3)}} C_{\pi N} A_{3/2}$$

where

$$\alpha = \sqrt{\frac{k}{\pi q}\frac{1}{(2j+1)}\frac{M_N}{M_R}\frac{\Gamma_\pi}{\Gamma^2}}$$

and where k and q are respectively the photon and pion centre of mass momenta, Γ is the resonance width, Γ_π is the partial width for decay to πN and $C_{\pi N}$ is the Clebsch-Gordan coefficient for decay into the relevant charge state.

Because of this, and particularly because of the presence of the width terms, the couplings usually quoted are often not an indication of the size of the contribution to the photoproduction amplitudes.

(9)

Also, if the partial width to γN is poorly known, there is often a large uncertainty in the size, but not the sign of the γN coupling.

Resonance dominance

The imaginary parts of the partial waves, and invariant amplitudes are mainly made from resonance contributions.

This works for other than the S waves and the P11, P13 and P31 partial waves.

Except for the $\Delta(1232)$, the resonances are given by by Breit-Wigner resonance forms with a fixed width.

Effectively, this is placing poles for the resonances under the s and u channel cuts.

Fitting the data

The advantages of using fixed-t dispersion relations are

- Only four parametrised numbers for each reaction, energy and angle
- Fewer free parameters
- Less ambiguous solutions
- The effects of analyticity are built in

The disadvantages are

- It is necessary to solve simultaneously over as large an energy range as possible. The analysis uses data from threshold to E_γ of 16 GeV.
- The used of fixed t requires an extrapolation of the imaginary parts outside the physical range of θ, the centre of mass production angle. The series expansion in $\cos(\theta)$ is known to diverge
- It requires much numerical integration for each function call during the minimisation.

The energy range for the dispersion integrands involving the imaginary parts of the amplitudes is in three parts

- In the lowest energy range, currently from threshold to W of 2 or 2.1 GeV, the integrands are parametrised in terms of resonances. The range of t for data is limited to greater than $-1.5\ GeV^2$
- In the highest energy range, for W greater than 2.5 GeV, the integrands are given by a Regge parametrisation. This is limited to t greater than $-1.0\ GeV^2$.
- In the intermediate region, the low energy resonance parametrisation switches smoothly and linearly to the Regge form.

In each case, the real parts are calculated by the dispersion integrals.

The analysis fits data from threshold to photon energies of 16 GeV.

Data has been used for all four reactions.

$\gamma p \rightarrow \pi^+ n$

$\gamma p \rightarrow \pi^0 p$

$\gamma n \rightarrow \pi^- p$

$\gamma n \rightarrow \pi^0 n$ (very little)

Neutron target data is needed even for fits to proton target data since it gives part of the u channel contribution.

The observables are

differential cross section – $\frac{d\sigma}{d\Omega}$

recoil nucleon polarisation – P

polarised photon asymmetry – Σ

Polarised target asymmetry – T

Double polarisation parameters – G and H.

Different type of observable are given weightings when minimising during the fitting process to ensure that they are not “outvoted” by other observables with many more data points.

Typical fit

W = 1.125 to 2500 GeV W_1 = 2.0 GeV

Reaction	Obs	N	χ^2/N
$\gamma p \to \pi^+ n$	$\frac{d\sigma}{d\Omega}$	3843	1.266
	P	209	1.417
	Σ	949	1.325
	T	657	2.059
	G	77	3.553
	H	77	3.031
$\gamma p \to \pi^0 p$	$\frac{d\sigma}{d\Omega}$	3112	1.299
	P	374	1.854
	Σ	1223	1.416
	T	657	1.656
	G	59	0.754
	H	59	0.657
$\gamma n \to \pi^- p$	$\frac{d\sigma}{d\Omega}$	375	0.679
	Σ	87	0.574
	$R(\pi^-/\pi^+)$	11	0.226
all data		11442	1.371

Regge region

$W > 2.5$ GeV all data 377 pts 1.647

The P_{33} partial waves

The solutions for the P33 waves must have complex phases that satisfy Watson's theorem across the Δ(1232).

It must to be possible to add further resonances at higher energies.

The method used modifies one originally given by Engels and Schmidt. (Phys. Rev. 169, 1296 (1968)).

The first resonance region and the Δ(1232)

This is fitted at the same time simultaneously with all the other resonances and the Regge parametrisation.

The P_{33} phase shift is parametrised using a simple Breit-Wigner resonance.

Only five free parameters are needed for the P_{33} and all other partial waves are parameter free.

The couplings

The values obtained for the couplings to γN are

$A_{1/2}$ = -0.151 $GeV^{-1/2}$

$A_{3/1}$ = -0.263 $GeV^{-1/2}$

These agree closely with almost all other measurements.

The mass and width of the Δ^+

The mass is taken to be the point where the complex phase is 90 degrees.

$M(\Delta^+)$ = 1231.3 ± 0.8 GeV

This fits well with the masses of the Δ^{++} and Δ^0 from πN elastic scattering. For example, Abaev 95 gives

$M(\Delta^{++})$ = 1230.5 ± 0.2 GeV

$M(\Delta^0)$ = 1233.1 ± 0.3 GeV

The value obtained for the width

$\Gamma(\Delta^+)$ = 109 ± 2 GeV.

E/M ratio

This is the ratio, at the resonance mass.

$$\mathrm{Im}\,E^{(3)}_{1+}(W_R)\,/\,\mathrm{Im}\,M^{(3)}_{1+}(W_R) \;=\; 2.48 \pm 0.28\,\%$$

S_{11}

N*(1535) ****

	This work	PDG BW (PDG ****)	PDG Pole (Mine ****)
Mass	1504 +- 13	1520 to 1555	1495 to 1515
Width	87 +- 10	100 to 200	90 to 250

	This work	PDG	VPI/GWU	QM	VPI/GWU corrected for my W, Γ, $Γ_π$ ↓
A1/2p	93 +- 6	73+-14	60+-15 *	93	69 ± 17
A1/2n	-63 +- 23	-76+-32	-20+-35 *	-63	-20 ± 35

N*(1650) ****

	This work	PDG BW (***)	PDG Pole (***)
Mass	1664 +- 2	1640 to 1680	1640 to 1680
Width	117 +- 13 Narrow	145 to 190	150 to 170

	This work	PDG	VPI/GWU	QM	
A1/2p	38 +- 4	48+-16	74+-1 *	54	78 ± 1
A1/2n	-5 +- 14 small	-17+-37	-28+-4	-35	-23 ± 40

N*(2090) *

	This work	PDG BW	PDG Pole (*)
Mass	*2211* +- *27*	2180+-80	2150+-70
Width	*256* +- *156*	350+-100	350+-100

	This work	PDG	GWU/VPI	QM
A1/2p	*63* +- *50*	-	-	12
A1/2n	!	-	-	-4

P_{11}

N*(1440) ****

	This work	PDG BW	PDG Pole
		***	***
Mass	1409 +- 5	1430 to 1470	1345 to 1385
Width	192 +- 23	250 to 450	160 to 260

	This work	PDG	VPI/GWU	QM	
A1/2p	-78 +- [redacted] 5	-69+-7	-67+-2	13	-64 ± 2
A1/2n	82 +- 8 *	37+-19	47+-5	-11	45 ± 5

N*(1710) ***

	This work	PDG BW	PDG Pole
		***	***
Mass	1750 # Fixed	1680 to 1740	1670 to 1770
Width	100 # Fixed	50 to 250	80 to 380

	This work	PDG	VPI/GWU	QM	
A1/2p	8 +- 19	-5+-23	7+-15	13	7 ± 15
A1/2n	-1 +- 15	-12+-30	-2+-15	-11	-2 ± 15

Very weak coupling

N*(2100) *

	This work	PDG BW	PDG Pole
			*
Mass	2093 +- 80	2125+-75(C)	2120+-40(C)
Width	138 to 500*	260+-100(C)	240+-80(C)

	This work	PDG	VPI/GWU	QM
A1/2p	24 +- 17	-	-	
A1/2n	!	-	-	

P_{13} –

N*(1550) ??

	This work	PDG BW	PDG Pole ?
Mass	1444 +- 22	-	-
Width	[redacted] 95 to 276	-	-

	This work	PDG	VPI/GWU	QM
A1/2p	23 +- 38	-	-	-
A3/1p	-74 +- 35 *	-	-	-
A1/2n	-14 +- 33	-	-	-
A3/1n	-53 +- 29 *	-	-	-

N*(1720) ****

	This work	PDG BW ***	PDG Pole ***
Mass	1721 +- 9	1650 to 1750	1650 to 1750
Width	143 +- 32	100 to 200	100 to 390

	This work	PDG	VPI/GWU	QM	
A1/2p	61 +- 12	52+-39	-15+-15	-11	-15 ± 15
A3/1p	-18 +- 21	-35+-24	7+-10	-31	7 ± 10
A1/2n	29 +- 15	-2+-26	7+-15	4	7 ± 15
A3/1n	-43 +- 33	-42+-94	-5+-25	11	-5 ± 25

N*(1900) **

	This work	PDG BW	PDG Pole **?
Mass	1911 +- 38 ✓	1879+-17(M)	-
Width	265 +- 102 ✓	498+-78(M)	-

	This work	PDG	VPI/GWU	QM
A1/2p	59 +- 22 ✓	-	-	-2, -21 or -5
A3/1p	-35 +- 14 ✓	-	-	-15, -27 or 2
A1/2n	20 +- 20	-	-	14, 10, or -2
A3/1n	-22 +- 29	-	-	19, 25 or 3

D_{13}

N*(1520) ****

	This work	PDG BW (****)	PDG Pole (****)
Mass	1499 +- 1	1515 to 1530	1505 to 1515
Width	127 +- 3	110 to 135	110 to 120

	This work	PDG	VPI/GWU	QM	
A1/2p	-18 +- 1	-22+-10	-24+-2	-15	− 27 ± 2
A3/1p	165 +- 3	167+-10	135+-2 ×	134	+ 152 ± 2
A1/2n	-77 +- 6	-65+-13	-67+-4	-38	− 75 ± 4
A3/1n	-133 +- 3	-144+-14	-122+-3	-114	− 137 ± 3

N*(1700) ***

	This work	PDG BW (**)	PDG Pole (**)
Mass	1747 +- 12 ✓	1650 to 1750	1630 to 1730
Width	98 +65 −11 ✓	50 to 150	50 to 150

	This work	PDG	VPI/GWU	QM
A1/2p	-19 +- 3 ✓	-22+-12	-	-33
A3/1p	-12 +- 12	0+-19	-	-3
A1/2n	27 +- 22	0+-56	-	18
A3/1n	39 +- 19 ✓	-2+-44	-	-30

N*(~~1940~~ 1890) **

	This work	PDG BW	PDG Pole (* (or **))
Mass	1886 +- 30	1880+-100(C)	1880+-100(C)
Width	271 [redacted] +30 −120	180+-60(C)	160+-80

	This work	PDG	VPI/GWU	QM
A1/2p	10 +15 −5	-	-	✓ 36 [1960?]
A3/1p	-50 +- 16 ✓	-	-	✓ -43 [1960?]
A1/2n	*24 +- 25*	-	-	-3 [1960?]
A3/1n	*-64 +- 63*	-	-	27 [1960?]

D_{13} Cont.

N*(2080) * | | * ?

	This work	PDG BW	PDG Pole
Mass	*2207 + 193 − 40*	2060+-80(C)	2050+-70(C)
Width	*150* to 264*	300+-100(C)	200+-80(C)

	This work	PDG	VPI/GWU	QM
A1/2p	*22 +- 20*	-	-	16 [2095?]
A3/1p	*13 + 40 − 6*	-	-	0 [2095?]
A1/2n	!	-	-	
A3/1n	!	-	-	

D_{15}

N*(1675) **** | **** | ****

	This work	PDG BW	PDG Pole
Mass	1673 +- 13	1670 to 1685	1655 to 1665
Width	154 +- 16	140 to 180	125 to 155

	This work	PDG	VPI/GWU	QM	
A1/2p	8 +- 3	19+-12	33+-4	2	30 ± 4
A3/1p	21 +- 2	19+-12	9+-3	3	8 ± 3
A1/2n	-60 +- 11	-47+-23	-50+-4	-35	−44 ± 9
A3/1n	-83 +- 10	-69+-19	-71+-5	-51	−46 ± 9

N*(2200) **

	This work	PDG BW	PDG Pole
Mass	*2237 +- 37*	2180+-80(C)	2100+-60(C)
Width	*357 +- 51*	400+-100(C)	360+-80(C)

	This work	PDG	VPI/GWU	QM
A1/2p	*113 +- 30* *	-	-	
A3/1p	*-149 +- 41* *	-	-	
A1/2n	!	-	-	
A3/1n	!	-	-	

Mass too high to

F_{15}

N*(1680) ****

	This work	PDG BW	PDG Pole
		****	****
Mass	1674 +- 1	1675 to 1690	1665 to 1675
Width	115 +- 2	120 to 140	105 to 135

	This work	PDG	VPI/GWU	QM	
A1/2p	-11 +- 3	-17+-10	-13+-2	-38	-14 ± 2
A3/1p	134 +- 3	127+-12	129+-2	56	135 ± 2
A1/2n	27 +- 13	31+-13	29+-6	19	30 ± 6
A3/1n	-32 +- 16	-30+-14	-58+-9	-23	-61 ± 9

N*(2000) **

	This work	PDG BW	PDG Pole
			*
Mass	1850*	1903+-87 (M)	-
Width	200*	490 +- 310 (M)	-

	This work	PDG	VPI/GWU	QM
A1/2p	-2 +- 19	-	-	
A3/1p	99 +- 30 ✓	-	-	
A1/2n	10 +- 52	-	-	
A3/1n	52 +- 91	-	-	

Mass and width on lower limits

Chosen fit

F_{17}

N*(1990) ** * *

	This work		PDG BW	PDG Pole
Mass	*2179 +- 46*	×	1970 +-50 (C)	1900+-30(C)
Width	*317 +- 60*		350 +- 120 (C)	260+-60(C)

	This work	PDG	VPI/GWU	QM
A1/2p	*-135 +- 39*	-	-	-1
A3/1p	*232 +- 71*	-	-	-2
A1/2n	!	-	-	-15
A3/1n	!	-	-	-18

Mass is high

G_{17}

N*(2190) **** * **

	This work	PDG BW	PDG Pole
Mass	2030 +- 50	2100 to 2200	1950 to 2150
Width	229 +- 58	350 to 550	350 to 550

	This work	PDG	VPI/GWU	QM
A1/2p	-61 +- 27	-	-	-34
A3/1p	97 +- 40	-	-	28
A1/2n	!	-	-	10
A3/1n	!	-	-	-14

Narrow width ?

G_{19}

-

N*(2250) ****

	This work	PDG BW	* PDG Pole
Mass	2000* ✗	2170 to 2310	2080 to 2200
Width	700* ✗	290 to 470	280 to 680

Mass on lower limit, width on upper limit

	This work	PDG	VPI/GWU	QM
A1/2p	31 +- 4	-	-	0
A3/1p	-49 +- 18	-	-	1
A1/2n	!	-	-	-14
A3/1n	!	-	-	-17

H_{19}

N*(2250) ****

	This work	PDG BW	? PDG Pole
Mass	*2194 +- 201* ✓	2180 to 2310	2100 to 2240
Width	*413 +- 113* ✓	320 to 550	370 to 570

	This work	PDG	VPI/GWU	QM
A1/2p	*-39 +- 69* ✗	-	-	
A3/1p	*116 +- 81* ✗	-	-	
A1/2n	!	-	-	
A3/1n	!	-	-	

S_{31}

Δ(1620)

	**** This work	** PDG BW	*** PDG Pole	
Mass	1608 +- 6	1615 to 1675	1580 to 1620	
Width	91 to 116	120 to 180	100 to 130	

	This work	PDG	VPI/GWU	QM
A1/2	23 to 37	27+-11	-13+-3	81 −14 ± 3

Δ(1900)

	** This work	* PDG BW	* PDG Pole
Mass	1732 +- 6	1850 to 1950(C	1870 +- 40 (C)
Width	276 +- 51	140 to 240 (C)	180+-50 (C)

	This work	PDG	VPI/GWU	QM
A1/2	61 +- 32	13+-16	-	20

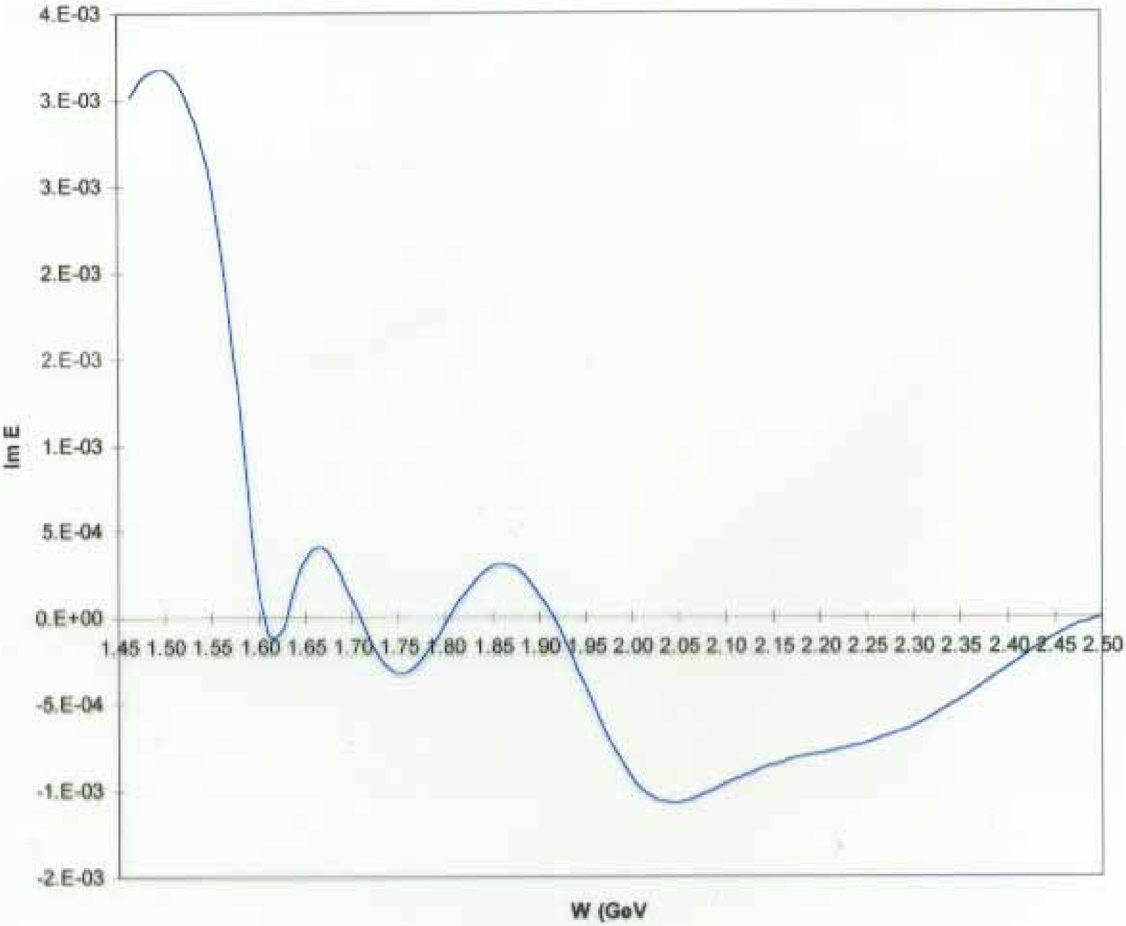
Δ(2150)

	* This work	PDG BW	* PDG Pole
Mass	2005 +- 45	2150+-100 (C)	2140+-40 (C)
Width	350* × upper limit	200+-100 (C)	200+-80 (C)

	This work	PDG	VPI/GWU	QM
A1/2	84 +- 49	-	-	12 or 20

BACKGROUND PROBLEMS

S31



4.E-03
3.E-03
3.E-03
2.E-03
2.E-03
1.E-03
5.E-04
0.E+00
-5.E-04
-1.E-03
-2.E-03
Im E
1.45 1.50 1.55 1.60 1.65 1.70 1.75 1.80 1.85 1.90 1.95 2.00 2.05 2.10 2.15 2.20 2.25 2.30 2.35 2.40 2.45 2.50
W (GeV

Chosen fit

P_{31} –

Δ(1540) ?? ?

	This work	PDG BW	PDG Pole
Mass	1480 to 1536	-	-
Width	80 to 142	-	-

	This work	PDG	VPI/GWU	QM
A1/2	28 +- 21			

Δ(1750) * *

	This work	PDG BW	PDG Pole
Mass	1705 +- 55	1721+-61 (V)	1714 (V)
Width	100 to 300	70+-50 (V)	68 (V)

	This work	PDG	VPI/GWU	QM
A1/2	31 +- 21	-	-	

Δ(1910) ****

	This work	PDG BW *	PDG Pole *
Mass	1809 to 1920	1870 to 1920	1880 +- 30 (C)
Width	150* to 500*	190 to 270	200 +- 40

	This work	PDG	GWU	QM
A1/2	7 +- 12	3+-14	-2+-8	-2 ± 9

Chosen fit

P_{33}

Δ(1232)

	****	****	****
	This work	PDG BW	PDG Pole
Mass	1231.3 +- 0.8	1230 to 1234	
Width	109.3 +- 2.1	115 to 125	

	This work	PDG	VPI/GWU	QM	
A1/2	-151 +- 1	-135+-6	-129+-1	-108	-124 ± 1
A3/2	-263 +- 2	-255+-8	-243+-1	-186	-234 ± 1

E/M -2.476 +- 0.282

Δ(1600)

	***	***	***?
	This work	PDG BW	PDG Pole
Mass	1685 +- 53	1550 to 1700	1500 to 1700
Width	208 +- 58	250 to 450	200 to 400

	This work	PDG	VPI/GWU	QM	
A1/2	-21 +- 5	-22+-29	-18+-15	30	-18 ± 15
A3/2	-10 +- 8	1+-22	-25+-15	51	-25 ± 15

Δ(1920)

	***	*	*
	This work	PDG BW	PDG Pole
Mass	2004 +- 104	1900 to 1970	1850 to 1950
Width	150* Lower limit	150 to 300	200 to 400

	This work	PDG	VPI/GWU	QM
A1/2	-26 +- 13	-	-	
A1/2	1 +- 18	-	-	

D_{33}

–

Δ(1700) ****

****

****

	This work		PDG BW	PDG Pole
Mass	1609 +-	12	1670 to 1770	1620 to 1700
Width	262 +-	14	200 to 400	150 to 250

	This work		PDG	VPI/GWU	QM	
A1/2	83 +-	7	104+-15	89+-10	82	116 ± 13
A3/2	100 +-	9	85+-22	92+-7	68	120 ± 9

Δ(1940) *

*

	This work		PDG BW	PDG Pole
Mass	1876 +-	60	1940+-100 (C)	1900+-100 (C)
Width	650*		200+-100 (C)	200+-60 (C)

	This work		PDG	VPI/GWU	QM
A1/2	-9 +-	11	-36+-58 (A)	-	-20
A3/2	-98 +-	12	-31+-12 (A)	-	-6

wide !

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D$_{35}$

Δ(1930) *** **

	This work	PDG BW	PDG Pole
	***	**	*
Mass	1800* to 1927	1920 to 1970	1840 to 1940
Width	180* to 419	250 to 450	200 to 300

	This work	PDG	VPI/GWU	QM	
A1/2	-3 +- 6	-9+-28	4+-6	11	3 ± 5
A3/2	10 +- 8	-18+-28	-3+-6	19	-3 ± 5

Δ(2350) *

	This work	PDG BW	PDG Pole
Mass	*2300 +- 70*	2400+-125 (C)	2400+-125 (C)
Width	*272 to 500**	400+-150 (C)	400+-150 (C)

	This work	PDG	VPI/GWU	QM
A1/2	*neg?*	-	-	
A3/2	*neg?*	-	-	

F_{35}

Δ(1905) ****

	This work	PDG BW **	PDG Pole **
Mass	1837 +- 29	1870 to 1920	1800 to 1860
Width	159 +- 39	280 to 440	230 to 330

	This work	PDG	VPI/GWU	QM	
A1/2	21 +- 7	26+-11	2+-5	10	2 ± 5
A3/2	-26 +- 10	-45+-20	-56+-5	16	-61 ± 5

Δ(2350) *

	This work	PDG BW	PDG Pole
Mass	*2350**	2200+-125 (C)	2150+-100 (C)
Width	*550**	400+-125 (C)	350+-100 (C)

	This work	PDG	VPI/GWU	QM
A1/2	neg?	-	-	27
A3/2	neg??	-	-	107

F_{37}

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Δ(1950) ****

	This work	PDG BW ****	PDG Pole ****
Mass	1887 +- 12	1940 to 1960	1880 to 1890
Width	251 +- 16	290 to 350	210 to 270

	This work	PDG	VPI/GWU	QM	
A1/2	-47 +- 2	-76+-12	-64+-4	-33	-76 ± 5
A3/2	-58 +- 3	-97+-10	-80+-3	-42	-94 ± 4

Δ(2390) *

	This work	PDG BW	PDG Pole
Mass	*2300**	2350+-100 (C)	2350+-100 (C)
Width	*214 +- 72*	260+-100 (C)	300+-80 (C)

	This work	PDG	VPI/GWU	QM
A1/2	pos?	-	-	-33
A3/2	pos?	-	-	-42

G_{37}

Δ(2220) ****

	This work	PDG BW	PDG Pole
Mass	*2298 +- 48*	2200+-100 (C)	2100+-50 (C)
Width	*450 +- 98*	450+-100(C)	340+-80 (C)

	This work	PDG	VPI/GWU	QM
A1/2	!	-	-	14
A3/2	!	-	-	-4

G_{39}

–

Δ(2390) *

	This work	PDG BW	PDG Pole
Mass	*2244 +- 41*	2300+-100 (C)	2260+-60 (C)
Width	*299 +- 6*	330+-100 (C)	320+-160 (C)

	This work	PDG	VPI/GWU	QM
A1/2	neg?	-	-	
A3/2	!	-	-	

H_{39}

Δ(2300) **

	This work	PDG BW	PDG Pole
Mass	*2450**	2400+-125 (C)	2370+-80 (C)
Width	*376 +- 115*	425+-150 (C)	420+-160 (C)

	This work	PDG	VPI/GWU	QM
A1/2	!	-	-	-14
A3/2	!	-	-	-17

$H_{3,11}$

Δ(2420) ****

	This work	PDG BW	PDG Pole
Mass	*2300**	2300 to 2500	2260 to 2400
Width	*335 +- 10*	300 to 500	350 to 750

	This work	PDG	VPI/GWU	QM
A1/2	!	-	-	
A3/2	neg?	-	-	

*	=	On imposed limit
#	=	Value fixed
!	=	Mass to high for value to have meaning

Italics mean mass is in the intermediate region
and values may not be reliable

(A)	=	AWAJI 81
(C)	=	CUTKOSKY 80
(M)	=	MANLEY 92
(V)	=	VRANA 00