

**$\Delta(1600) P_{33}$**

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+) \text{ Status: } ***$$

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** (1982).

The various analyses are not in good agreement.

### $\Delta(1600)$ BREIT-WIGNER MASS

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1550 to 1700 (<math>\approx</math> 1600) OUR ESTIMATE</b>			
1706 $\pm$ 10	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
1600 $\pm$ 50	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
1522 $\pm$ 13	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1667 $\pm$ 1	PENNER	02C	DPWA Multichannel
1687 $\pm$ 44	VRANA	00	DPWA Multichannel
1672 $\pm$ 15	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
1706	LI	93	IPWA $\gamma N \rightarrow \pi N$
1690	BARNHAM	80	IPWA $\pi N \rightarrow N\pi\pi$
1560	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
1640	<sup>2</sup> LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

### $\Delta(1600)$ BREIT-WIGNER WIDTH

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>250 to 450 (<math>\approx</math> 350) OUR ESTIMATE</b>			
430 $\pm$ 73	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
300 $\pm$ 100	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
220 $\pm$ 40	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
397 $\pm$ 10	PENNER	02C	DPWA Multichannel
493 $\pm$ 75	VRANA	00	DPWA Multichannel
315 $\pm$ 20	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
215	LI	93	IPWA $\gamma N \rightarrow \pi N$
250	BARNHAM	80	IPWA $\pi N \rightarrow N\pi\pi$
180	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
300	<sup>2</sup> LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

### $\Delta(1600)$ POLE POSITION

#### REAL PART

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1500 to 1700 (<math>\approx</math> 1600) OUR ESTIMATE</b>			
1550	<sup>3</sup> HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1550 $\pm$ 40	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

• • • We do not use the following data for averages, fits, limits, etc. • • •

1599	VRANA	00	DPWA	Multichannel
1675	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
1612	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90
1609 or 1610	<sup>4</sup> LONGACRE	78	IPWA	$\pi N \rightarrow N\pi\pi$
1541 or 1542	<sup>1</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

### –2×IMAGINARY PART

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>200 to 400 (<math>\approx</math> 300) OUR ESTIMATE</b>			
200 ± 60	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

• • • We do not use the following data for averages, fits, limits, etc. • • •

312	VRANA	00	DPWA	Multichannel
386	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
230	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90
323 or 325	<sup>4</sup> LONGACRE	78	IPWA	$\pi N \rightarrow N\pi\pi$
178 or 178	<sup>1</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

## $\Delta(1600)$ ELASTIC POLE RESIDUE

### MODULUS $|r|$

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
17 ± 4	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

• • • We do not use the following data for averages, fits, limits, etc. • • •

52	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
16	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

### PHASE $\theta$

<u>VALUE (°)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
–150 ± 30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

• • • We do not use the following data for averages, fits, limits, etc. • • •

+ 14	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
– 73	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

## $\Delta(1600)$ DECAY MODES

The following branching fractions are our estimates, not fits or averages.

Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1$ $N\pi$	10–25 %
$\Gamma_2$ $\Sigma K$	
$\Gamma_3$ $N\pi\pi$	75–90 %
$\Gamma_4$ $\Delta\pi$	40–70 %
$\Gamma_5$ $\Delta(1232)\pi$ , <i>P</i> -wave	
$\Gamma_6$ $\Delta(1232)\pi$ , <i>F</i> -wave	
$\Gamma_7$ $N\rho$	<25 %

$\Gamma_8$	$N\rho, S=1/2, P\text{-wave}$	
$\Gamma_9$	$N\rho, S=3/2, P\text{-wave}$	
$\Gamma_{10}$	$N\rho, S=3/2, F\text{-wave}$	
$\Gamma_{11}$	$N(1440)\pi$	10–35 %
$\Gamma_{12}$	$N(1440)\pi, P\text{-wave}$	
$\Gamma_{13}$	$N\gamma$	0.001–0.02 %
$\Gamma_{14}$	$N\gamma, \text{helicity}=1/2$	0.0–0.02 %
$\Gamma_{15}$	$N\gamma, \text{helicity}=3/2$	0.001–0.005 %

### $\Delta(1600)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{\text{total}}$					$\Gamma_1/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>0.10 to 0.25 OUR ESTIMATE</b>					
0.12±0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N \ \& \ N\pi\pi$	
0.18±0.04	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$	
0.21±0.06	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.13±0.01	PENNER	02C	DPWA	Multichannel	
0.28±0.05	VRANA	00	DPWA	Multichannel	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Sigma K$					$(\Gamma_1\Gamma_2)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>–0.36 to –0.28 OUR ESTIMATE</b>					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.006 to 0.042	<sup>5</sup> DEANS	75	DPWA	$\pi N \rightarrow \Sigma K$	

Note: Signs of couplings from  $\pi N \rightarrow N\pi\pi$  analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the  $\Delta(1620) S_{31}$  coupling to  $\Delta(1232)\pi$ .

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi, P\text{-wave}$					$(\Gamma_1\Gamma_5)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>+0.27 to +0.33 OUR ESTIMATE</b>					
+0.29±0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N \ \& \ N\pi\pi$	
+0.24±0.05	BARNHAM	80	IPWA	$\pi N \rightarrow N\pi\pi$	
+0.34	<sup>1,6</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	
+0.30	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$	

$\Gamma(\Delta(1232)\pi, P\text{-wave})/\Gamma_{\text{total}}$					$\Gamma_5/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
0.59±0.10	VRANA	00	DPWA	Multichannel	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi, F\text{-wave}$					$(\Gamma_1\Gamma_6)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>–0.15 to –0.03 OUR ESTIMATE</b>					
–0.07	<sup>1,6</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N\rho, S=1/2, P\text{-wave}$	$(\Gamma_1 \Gamma_8)^{1/2} / \Gamma$
VALUE	DOCUMENT ID TECN COMMENT
+0.10	1,6 LONGACRE 77 IPWA $\pi N \rightarrow N\pi\pi$

  

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N\rho, S=3/2, P\text{-wave}$	$(\Gamma_1 \Gamma_9)^{1/2} / \Gamma$
VALUE	DOCUMENT ID TECN COMMENT
+0.10	1,6 LONGACRE 77 IPWA $\pi N \rightarrow N\pi\pi$

  

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N(1440)\pi, P\text{-wave}$	$(\Gamma_1 \Gamma_{12})^{1/2} / \Gamma$
VALUE	DOCUMENT ID TECN COMMENT
<b>+0.15 to +0.23 OUR ESTIMATE</b>	
+0.16 ± 0.02	MANLEY 92 IPWA $\pi N \rightarrow \pi N \& N\pi\pi$
+0.23 ± 0.04	BARNHAM 80 IPWA $\pi N \rightarrow N\pi\pi$

  

$\Gamma(N(1440)\pi) / \Gamma_{\text{total}}$	$\Gamma_{11} / \Gamma$
VALUE	DOCUMENT ID TECN COMMENT
0.13 ± 0.04	VRANA 00 DPWA Multichannel

### $\Delta(1600)$ PHOTON DECAY AMPLITUDES

#### $\Delta(1600) \rightarrow N\gamma$ , helicity-1/2 amplitude $A_{1/2}$

VALUE ( $\text{GeV}^{-1/2}$ )	DOCUMENT ID	TECN	COMMENT
<b>-0.023 ± 0.020 OUR ESTIMATE</b>			
-0.018 ± 0.015	ARNDT 96	IPWA	$\gamma N \rightarrow \pi N$
-0.039 ± 0.030	CRAWFORD 83	IPWA	$\gamma N \rightarrow \pi N$
-0.046 ± 0.013	AWAJI 81	DPWA	$\gamma N \rightarrow \pi N$
0.005 ± 0.020	CRAWFORD 80	DPWA	$\gamma N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
0.0	PENNER 02D	DPWA	Multichannel
-0.026 ± 0.002	LI 93	IPWA	$\gamma N \rightarrow \pi N$
-0.200	<sup>7</sup> WADA 84	DPWA	Compton scattering
0.000 ± 0.030	BARBOUR 78	DPWA	$\gamma N \rightarrow \pi N$
0.0 ± 0.020	FELLER 76	DPWA	$\gamma N \rightarrow \pi N$

#### $\Delta(1600) \rightarrow N\gamma$ , helicity-3/2 amplitude $A_{3/2}$

VALUE ( $\text{GeV}^{-1/2}$ )	DOCUMENT ID	TECN	COMMENT
<b>-0.009 ± 0.021 OUR ESTIMATE</b>			
-0.025 ± 0.015	ARNDT 96	IPWA	$\gamma N \rightarrow \pi N$
-0.013 ± 0.014	CRAWFORD 83	IPWA	$\gamma N \rightarrow \pi N$
0.025 ± 0.031	AWAJI 81	DPWA	$\gamma N \rightarrow \pi N$
-0.009 ± 0.020	CRAWFORD 80	DPWA	$\gamma N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-0.024	PENNER 02D	DPWA	Multichannel
-0.016 ± 0.002	LI 93	IPWA	$\gamma N \rightarrow \pi N$
0.023	WADA 84	DPWA	Compton scattering
0.000 ± 0.045	BARBOUR 78	DPWA	$\gamma N \rightarrow \pi N$
0.0 ± 0.015	FELLER 76	DPWA	$\gamma N \rightarrow \pi N$

## Δ(1600) FOOTNOTES

- <sup>1</sup> LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to  $\pi N \rightarrow N\pi\pi$  data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- <sup>2</sup> From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- <sup>3</sup> See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of  $N$  and  $\Delta$  resonances as determined from Argand diagrams of  $\pi N$  elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- <sup>4</sup> LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to  $\pi N \rightarrow N\pi\pi$  data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- <sup>5</sup> The range given is from the four best solutions. DEANS 75 disagrees with  $\pi^+ p \rightarrow \Sigma^+ K^+$  data of WINNIK 77 around 1920 MeV.
- <sup>6</sup> LONGACRE 77 considers this coupling to be well determined.
- <sup>7</sup> WADA 84 is inconsistent with other analyses — see the Note on  $N$  and  $\Delta$  Resonances.

## Δ(1600) REFERENCES

For early references, see Physics Letters **111B** 70 (1982).

PENNER	02C	PR C66 055211	G. Penner, U. Mosel	(GIES)
PENNER	02D	PR C66 055212	G. Penner, U. Mosel	(GIES)
VRANA	00	PRPL 328 181	T.P. Vrana, S.A. Dytman., T.-S.H. Lee	(PITT+)
ARNDT	96	PR C53 430	R.A. Arndt, I.I. Strakovsky, R.L. Workman	(VPI)
ARNDT	95	PR C52 2120	R.A. Arndt <i>et al.</i>	(VPI, BRCO)
HOEHLER	93	$\pi N$ Newsletter 9 1	G. Hohler	(KARL)
LI	93	PR C47 2759	Z.J. Li <i>et al.</i>	(VPI)
MANLEY	92	PR D45 4002	D.M. Manley, E.M. Saleski	(KENT) IJP
Also	84	PR D30 904	D.M. Manley <i>et al.</i>	(VPI)
ARNDT	91	PR D43 2131	R.A. Arndt <i>et al.</i>	(VPI, TELE) IJP
WADA	84	NP B247 313	Y. Wada <i>et al.</i>	(INUS)
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)
PDG	82	PL 111B	M. Roos <i>et al.</i>	(HELS, CIT, CERN)
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)
Also	82	NP B197 365	K. Fujii <i>et al.</i>	(NAGO)
BARNHAM	80	NP B168 243	K.W.J. Barnham <i>et al.</i>	(LOIC)
CRAWFORD	80	Toronto Conf. 107	R.L. Crawford	(GLAS)
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP
Also	79	PR D20 2839	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP
HOEHLER	79	PDAT 12-1	G. Hohler <i>et al.</i>	(KARLT) IJP
Also	80	Toronto Conf. 3	R. Koch	(KARLT) IJP
BARBOUR	78	NP B141 253	I.M. Barbour, R.L. Crawford, N.H. Parsons	(GLAS)
LONGACRE	78	PR D17 1795	R.S. Longacre <i>et al.</i>	(LBL, SLAC)
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP
Also	76	NP B108 365	J. Dolbeau <i>et al.</i>	(SACL) IJP
WINNIK	77	NP B128 66	M. Winnik <i>et al.</i>	(HAIF) I
FELLER	76	NP B104 219	P. Feller <i>et al.</i>	(NAGO, OSAK) IJP
DEANS	75	NP B96 90	S.R. Deans <i>et al.</i>	(SFLA, ALAH) IJP
LONGACRE	75	PL 55B 415	R.S. Longacre <i>et al.</i>	(LBL, SLAC) IJP